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PROCESS PLANNING AND WEIGHTED SCHEDULING WITH WNOPPT WEIGHTED DUE-DATE ASSIGNMENT USING HYBRID SEARCH FOR WEIGHTED CUSTOMERS

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Abstract

Although scheduling with due date assignment and, integrated process planning and scheduling are two popular topics studied by researchers, there are few works on integration of process planning, scheduling and due date assignment. In this study integration of process planning and scheduling with weighted due date assignment is studied. Different level of integration of these three functions are tested. As a solution techniques random search and hybrid search are applied. Hybrid search starts with random search and continues with genetic search. Search results are compared with ordinary solutions and searches are found very useful and hybrid search outperformed random search. Hybrid search with full integration combination found as the best combination.

Keywords

Process Planning, Scheduling, Weighted Due-Date Assignment, Hybrid Search, Genetic Algorithm, Random Search

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1. Introduction

Traditionally process planning, scheduling and due date assignment are performed independently. Because of the dependence of these functions between each other, it is better to consider them concurrently. Although there are numerous works on IPPS (Integrated Process Planning and Scheduling) and many works on SWDDA (Scheduling With Due Date Assignment), IPPSDDA (Integrated Process Planning, Scheduling And Due Date Assignment) is a very new topic to study. Outputs of downstream functions become inputs to the upstream functions. For example, outputs of process planning are the inputs of scheduling. That's why these functions highly affect each other. Independently performed functions try to get local optima but do not consider global optima. If we integrate due date assignment with previous two functions we may assign best due dates for the jobs according to the given process plans and schedule. By doing so, we may increase global performance. Also if we integrate due date assignment with other two functions we may select best process plans for the given due date and we can schedule jobs better for the given due dates which significantly improves global performance.

Society of Manufacturing Engineers has defined process planning as the systematic determination of the methods by which a product is to be manufactured economically and competitively. According to (Zhang & Mallur, 1994) production scheduling is a resource allocator which considers timing information while allocating resources to the tasks. (Gordon, Proth,& Chu, 2002) stated that "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."

Since only scheduling problem belongs to NP-Hard class problem, integrated problems are even harder to solve. That is why heuristics are applied to solve the problem. Exact solutions are only possible for very small problem but when problem gets bigger we try to find a good solution instead of the exact optimum.

Recent developments in hardware, software and algorithms provided us to solve some problems which could not be solved earlier. After developments in these area, CAPP (Computer Aided Process Planning) is developed and it became easier to prepare process plans. So it is possible to prepare alternative and good process plans for scheduling that improves global performance.

At the literature due dates are given without aware of importance of the customers but in this study important customers are given relatively closer due dates. This greatly improves the solution performance. Less important customers are given relatively far due dates. As a due date assignment WNOPPT (Weighted Number of Operation plus Processing Time) method is used, where due dates are determined according to processing time of the job plus according to number of operations in that job. This results are converted due dates according to the weight of the customers where important customers get closer due dates.

If we look at the literature we can see tardiness or both earliness and tardiness or number of tardy jobs as penalty functions. But in this study we penalized all of earliness, tardiness and due dates multiplied with the weights of the jobs. So it is better to assign reasonably close due dates especially for important customers and we should keep our promise and we should minimize tardiness and we should not also finish jobs too early that cause inventory holding and other costs.

2. Related Researches

Although IPPSDDA is a very new area to study, we can see many works on IPPS and SWDDA problems. Since only scheduling problem is NP-Hard class problem integrated problems are even harder to solve. IPPSDDA problem is mentioned by (Demir, Taskin, & Cakar, 2004).

If we search literature for IPPSDDA, we can find only a few works. (Demir & Taskin, 2005) studied this subject in a Ph.D. Thesis and later (Demir et al., 2004) continued to study IPPSDDA problem. Later (Ceven & Demir, 2007) studied the benefit of integrating due date assignment with IPPS problem in an M.S. Thesis.

If we look at literature for IPPS problems we can observe that some researchers use genetic algorithm, some use evolutionary algorithms or agent based solutions to the problem. Some of the researchers decomposed the problem into smaller parts such as loading and scheduling subproblems. (Demir, Uygun, Cil, Ipek, & Sari, 2015).

If we give some surveys on IPPS we can see (Tan & Khosnevis, 2000) as a good literature survey on IPPS. We can also give (Li, Gao, Zhang, & Shao, 2010) and (Phanden, Jain & Verma, 2011) as surveys on IPPS problem.

If we look at earlier works on IPPS problem we can give following works on this problem. (Khosnevis & Chen, 1991), (Zhang & Mallur, 1994), (Brandimarte, 1999), (Morad & Zalzala, 1999) are some examples for the earlier works.

If we list some of the more recent works; (Tan & Khoshnevis, 2000), (Kim, Park & Ko, 2003), (Usher, 2003), (Tan & Khoshnevis, 2004), (Kumar & Rajotia, 2005), (Li et al., 2010), (Leung, Wong, Mak & Fung, 2010), (Phanden et al., 2011) are examples to the recent works.

Scheduling with due date assignment is also the other popular research topic and we can see numerous work on this problem. A state of the art review on scheduling with due date assignment is given by (Gordon et al., 2002) and it is better to see survey on SWDDA problem before studying this topic.

If we give some originalities of this study; Although SWDDA is studied, SWWDDA (scheduling with weighted due date assignment) is not mentioned. Here in this study we tried to assign relatively close due dates for the relatively more important customers and schedule according to these assigned due dates. Although traditionally tardiness is penalized, according to JIT philosophy both earliness and tardiness should be penalized. In this study we also penalized due dates besides earliness and tardiness. Since we give close due dates for important customers, we substantially reduce weighted due date and tardiness related costs. Another difference of this study is that we assign unique due dates for each customer but in the literature most of the works assign common due dates for the jobs waiting. Most of the works are on single machine scheduling but in this study we have m different machines n different jobs and we try to assign better due dates for each job and schedule these jobs on m different machines according to the given alternative routes of the jobs.

Due dates are determined externally or internally. At the former case we have no control over the due dates but at the latter case we can try to assign more suitable due dates for the jobs that minimize total penalty function.

When we look at literature we can see numerous works on SMSWDDA (Single Machine Scheduling with Due Date Assignment) and many works on MMSWDDA (Multiple Machine Scheduling with Due Date Assignment). Most of the works of literature assign common due dates for waiting jobs. In reality when jobs are going to be assembled, then they should be ready at the same time, so we should find best common due date for the parts waiting. But in this study as we mentioned earlier, n jobs are going to be scheduled before m machines and each of the jobs is to be assigned a unique due date. Every job has alternative routes and there is certain number of operations at every route.

If we list some works on SMSWDDA problem we can list following researches; (Ventura & Radhakrishan, 2003), (Wang, 2006), (Xia, Chen & Yue, 2008), (Gordon & Strusevich, 2009), and (Li, Yuan, Lee & Xu, 2011).

On the other hand if we list works on multiple machine case, following works are on MMSWDDA problem; (Adamapolous & Pappis, 1998), (Cheng & Kovalyov, 1999), and (Lauff & Werner, 2004).

3. Problem Studied

In this research we studied IPPSDDA problem. We tried to integrate process planning through alternative process plans with scheduling and due date assignment. We tested three shop floors which are small, medium and large shop floors. We used random search and hybrid search as solution techniques. We have n jobs to be scheduled with due date assignment, m machines and each job has alternative routes and each route has certain number of operations. As a due date assignment method we used WNOPPT technique, where due dates are determined according to weights of job, processing time of the selected route and number of operations at the selected route.

We have three shop floors and characteristics of each shop floors are given at Table 1. For example shop floor 1 has 20 machines, 50 jobs to be scheduled and due dates are to be assigned. Each job has 5 different alternative routes and each route has 10 operations. Processing times of each operations are distributed randomly according to the formula$\lfloor(12 + z * 6)\rfloor$. Practically operation times assume integer values in between 1 and 30, according to a normal distribution with mean 12 minutes and standard deviation is 6 minutes.

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

In this study we assumed one shift with 8*60 = 480 minutes. We penalized all earliness, tardiness and due date related costs. Penalty functions for each term are given below.

$$PD(j) = weight\ (j) * 8 * (D/480) \quad (1)$$

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

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

$$Penalty(j) = PD(j) + PE(j) + PT(j) \quad (4)$$

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

Where; $weight\ (j)$ is the importance of job$j$. D Is the assigned due date of job j, E is the earliness of job j and T is the tardiness of job j. $PD(j)$is penalty for due date, $PE(j)$ is the penalty for earliness and $PT(j)$ is the Penalty for tardiness of job j. $Penalty(j)$Is the total penalty for a job is determined by (4). Finally by using (5) we determine $Total\ Penalty$ which is the total penalty for all of the jobs is.

4. Solution Methods

We used two search techniques and ordinary solutions to compare. As undirected-directed search we used hybrid search and as undirected search we used random search. Each solution is explained below:

Ordinary Solution: At every step of iterations of random search and hybrid search we utilized three populations which are called as previous main population with size 10, current crossover population with size 8 and current mutation population with size 5. By using these three populations we select best 10 chromosomes out of 23 chromosomes of these populations and we determine current main population. We repeat iterations 200, 100, and 50 times according to the size of each shop floors. At the very beginning from three randomly produced populations we generate current main population for the first step. In short we select best 10 chromosomes of 23 randomly produced chromosomes. This best 10 chromosomes are used as ordinary solutions which mean no search is applied. These results are compared with the results of random search and hybrid search to illustrate the benefit of the searches.

Random Search: Here we applied 200, 100 and 50 random iterations for small, medium and large shop floors. At every iteration randomly we produce 8 chromosomes for crossover population and 5 chromosomes for mutation population. We used previous main population, current crossover population and current mutation population and we select best 10 chromosomes out of 23 chromosomes and produce current main population. Of course we didn't apply crossover or mutation here but in order to be fair in comparison with hybrid search we produce equal amount of chromosomes at every step.

Hybrid Search: Here we applied 200, 100 and 50 iterations according to the size of the shop floors as in random search, but initial iterations are random search iterations and later remaining iterations are genetic search iterations. For small shop floor at first we apply 50 random iterations and later we apply 150 genetic iterations. For medium shop floor at first we apply 25 random iterations and later we apply remaining 75 genetic iterations. For large shop floor we apply initially 15 random iterations and later we apply 35 genetic iterations. Here at first we applied random iterations because we wanted to scan solution space better at the beginning. Here if we produce a random number in between 0 and 1, at the first step expected value is 0.5 so marginal expectation is 0.5. If we generate two random numbers, then expected value of the maximum of these two values is 0.75 so marginal increase is 0.25. If we produce three random numbers, then expected value of the maximum of these three values is 0.875, so marginal increment is 0.125 and so on. So marginal increments are 0.5, 0.25, 0.125, 0.0625 and so on. So at the beginning random search is very useful but as iteration goes on marginal benefit decreases. That is why at the beginning we applied random search when marginal benefits are high and later we switched to genetic iterations which looks for better solution around best solutions obtained so far.

At the figure 1 below a sample chromosome is represented. At every chromosome we have (n+2) genes where first two genes are used to represent due date assignment rule and scheduling rule. Remaining n genes are used to represent current route of each job among alternatives. At the small and medium shop floors we have five alternative routes for every job. At the largest shop floor in order to decrease computational time of computer we have three alternative routes. Again here as in random search, marginal benefits of alternative routes are decreased as the alternative number increases. So, initial alternative routes are very beneficial but as the alternative route number increases marginal benefit gets decrease. This conclusion is based on the literature on the IPPS problems.

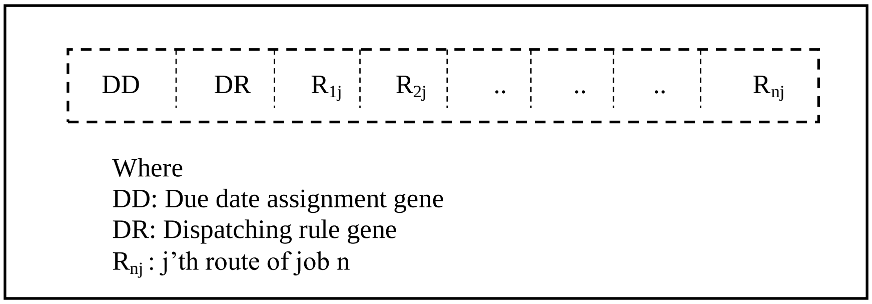

Figure 1: *Sample Chromosome*

Due dates are determined according to two main rules. First rule WNOPPT due date assignment rule is used to represent internal due date assignment and RDM rule is used for external due date assignment rule. With the multipliers for number of operations and multiplier for processing times we have WNOPPT main rule becomes nine different rules with different multipliers and with RDM due date assignment rule first gene assumes one of ten values. These rules are summarized at Table 2 below.

Table 2: *Due-Date Assignment Rules*

METHOD	MULTİPLİER1	MULTİPLİER2	RULE NO
WNOPPT	k_x =1, 2, 3	k_y =1, 2, 3	1, 2, 3, 4, 5, 6, 7, 8, 9
RDM	-	-	10

At the second gene of the chromosome dispatching rules can be one of nine different main rules. With the multipliers and weights of the jobs second gene assumes one of 21 values and these rules are listed at Table 3 below.

Table 3: *Dispatching Rules*

METHOD	MULTİPLİER	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

5. Comparisons Made

At this study ordinary solutions are compared with search results. Four ordinary solutions depending on different integration levels and five search results depending on different integration levels and search techniques are compared.

Four different ordinary solutions compared, depending on the different integration levels can be listed as follows; SIRO-RDM (Ordinary), SCH-RDM (Ordinary), SIRO-WNOPPT (Ordinary), and SCH-WNOPPT (Ordinary) are the ordinary solutions used in comparison.

If we list the five solutions of the random and hybrid searches according to the different integration levels:

SIRO-RDM (Hybrid): This is the lowest level of integration and due dates are determined randomly and jobs are scheduled in random order. And certain numbers of hybrid iterations (initially random and later genetic iterations) are applied. Below at Table 4 iteration combinations for each shop floor and search techniques are summarized.

SCH-RDM (Hybrid): Here we increased level of integration and 21 different dispatching rules are integrated with process plan selection but due dates are still determined randomly. Again certain number of hybrid iterations are applied depending on the size of the shop floor.

SIRO-WNOPPT (Hybrid): Here we integrated WNOPPT due date assignment rule with process plan selection but jobs are scheduled in random order. Benefit of integrating WNOPPT due date assignment with process plan selection but scheduling in random order cancel these benefits. Here again we applied certain number of hybrid iterations.

SCH-WNOPPT (Hybrid): Here every functions are integrated, process plan selection is integrated with 21 dispatching rules and due dates are determined according to the WNOPPT rules. This is the highest level of integration and hybrid iterations are used.

SCH-WNOPPT (Random): Since this is the highest level of integration and best combination we also tested this combination with random search. We applied predetermined number of random iterations.

Table 4: *Iteration Parameters*

	Shop Floor 1		Shop Floor 2		Shop Floor 3	
	Rnd. Iter. #	Genetic Iter. #	Rnd. Iter. #	Genetic Iter. #	Rnd. Iter. #	Genetic Iter. #
Random Search	200	-	100	-	50	-
Hybrid Search	50	150	25	75	15	35
Cpu time Aprox.	200 sec		500 sec		1000 sec	

Nine different solutions are compared. First four solutions are ordinary solutions depending on different integration levels. For every combination of integration level we also tested hybrid search and finally for the best combination we also tested random search. Ordinary solutions are found poor as expected and search results are found far better compared to ordinary solutions and hybrid search outperformed random search.

6. Experimental Study

We coded problem in C++ Language. Coded program performs random and genetic iterations and at each iteration it selects among alternative routes, assigns due dates, schedules jobs and calculate performance function value. We used Borland C++ 5.02 compiler while running the program. The program is run on a Laptop with 2 GHz processor and 8 GB Ram with windows 8.1 operating system. After we run the program we observed CPU times summarized at Tables 5, 6, and 7.

We tested nine solutions where four of them ordinary solutions, four of them hybrid search solutions and one of them was random search solution for different level of integration. First we tested fully unintegrated solution. Later we integrated functions one by one and at the end we tested fully integrated solution.

First shop floor we tested was small shop floor and characteristics of the shop floors are summarized at Table 1 in Section 3. We compared nine solutions for this shop floor also and ordinary solutions are found the poorest. Searches are found very useful and hybrid search found better compared to random according to the average results of the final population. We applied 200 iterations and iteration combinations are summarized at Table 4. CPU Times are given at Table 5 at the last column. It took in between 100 and 250 seconds to finish the program run at the background while all programs are running while using laptop. Results of small shop floor are summarized at Table 5 and Figure 2.

Table 5: *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 (H)	403.5	401.17	396.24	114 sec
SCH-RDM (H)	353.65	353.24	352.34	215 sec
SIRO-WNOPPT (H)	366.48	364.02	357.35	190 sec
SCH-WNOPPT (H)	309.03	308.46	307.87	215 sec
SCH-WNOPPT (R)	315.56	312.23	302.1	256 sec

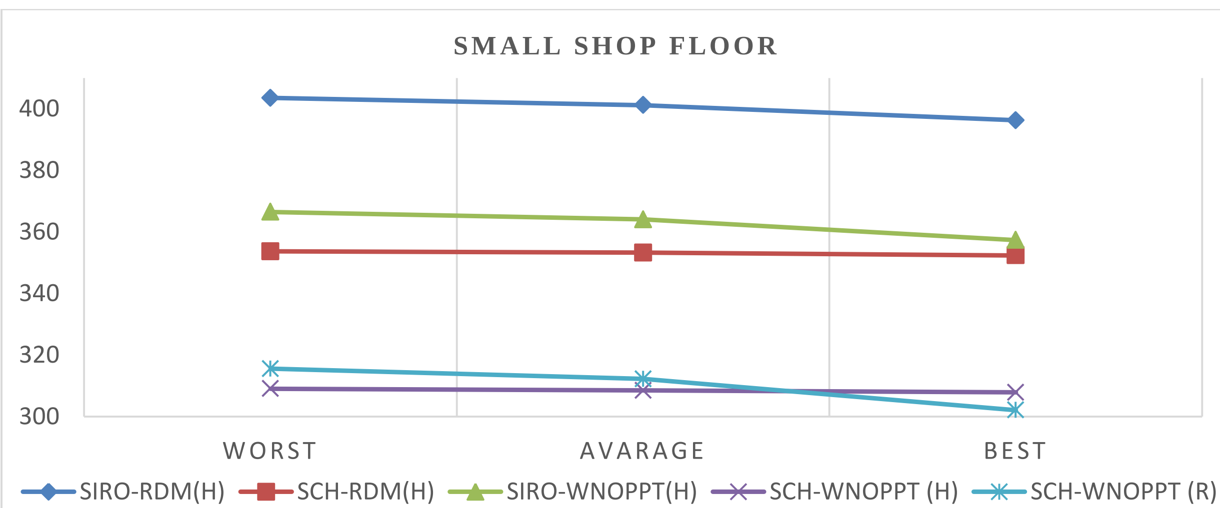

Figure 2: *Small Shop Floor Results*

We observed similar results at the second shop floor. These results are summarized at Table 6 and Figure 3. It took to finish the program run approximately in between 300 to 600 seconds. Again we found fully integrated level with hybrid search as the best combination. Iteration parameters are again given at Table 4 and we applied 100 iterations. Ordinary solutions were the poorest as expected and unintegrated combination was found poor combination. SIRO-WNOPPT combination found the poorest because even though we assign proper due dates for the jobs, SIRO scheduling deteriorates the result substantially.

Table 6: *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 (H)	983.48	976.4	964.51	294 sec
SCH-RDM (H)	797.79	793.96	790.96	534 sec
SIRO-WNOPPT (H)	992.32	988.94	983.38	347 sec
SCH-WNOPPT (H)	725.98	725.25	724.42	504 sec
SCH-WNOPPT (R)	760.58	753.93	732.54	678 sec

Figure 3: *Medium Shop Floor Results*

Here we tested largest shop floor and results are summarized at Table 7 and Figure 4. We applied 50 iterations and iteration combinations are summarized at the Table 4. To finish 100 iterations took approximately in between 700 and 1300 seconds. Here again as expected full integration level with hybrid search found best combination and unintegrated version found substantially inferior.

Table 7: *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 (H)	2528.85	2515.24	2495.2	669 sec
SCH-RDM (H)	2024.63	2020.64	2012.93	753 sec
SIRO-WNOPPT (H)	2380.72	2371.73	2360.71	667 sec
SCH-WNOPPT (H)	1728.56	1727.26	1724.69	1228 sec
SCH-WNOPPT (R)	1830.03	1810.09	1782.52	1350 sec

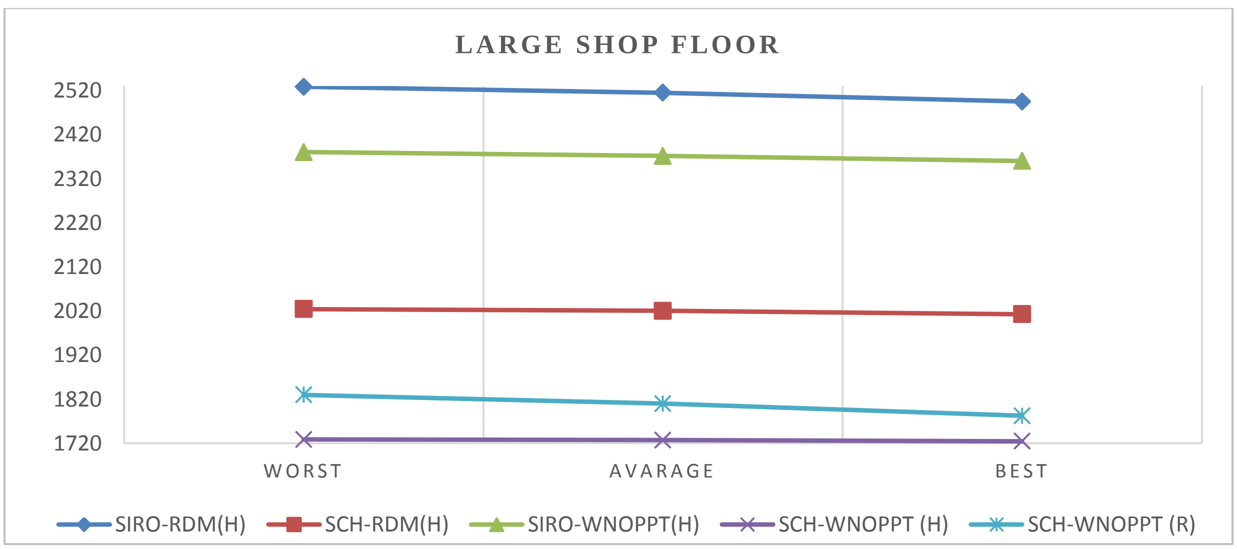

Figure 4: *Large Shop Floor Results*

7. Conclusion

Here we tested several important points in this study. First we tested different levels of integration to see whether integration is beneficial. Later we compared search results with ordinary solutions to see how searches are useful. Finally we compared hybrid search with random search.

There are some novel points in this research. First we tried to integrate three functions instead of two functions. There are numerous works on IPPS and SWDDA but there are only a few works on IPPSDDA problem. This work is on IPPSDDA. At the literature Due dates are assigned without taking into consideration of the weights of the jobs, but here we used weighted due date assignment. At the literature traditionally only tardiness is punished but according to JIT philosophy both earliness and tardiness should be punished. In this research we penalized all of weighted earliness, tardiness and due date related costs. In short here we studied integration of process planning and scheduling with weighted due date assignment.

Traditionally three functions is performed sequentially and separately. Since these functions highly affect each other, it is better to integrate these functions to improve global performance. Output of upstream functions becomes input to the downstream functions. Poorly prepared process plans becomes a poor input to the scheduling and substantially reduce shop floor performance and cause unbalanced machine loading. Also scheduling made without taking into account of due date assignment greatly deteriorate performance function. Due date assignment without considering dispatching assigns poor due dates. Since we penalized all of weighted earliness, tardiness and due date related costs, it is better to assign close due dates for important customers and schedule these customers first. By doing this we substantially save from punishment value.

In brief, we found full integration with hybrid search as the best combination. For better global performance integration level is very important and hybrid search out performs random search. Using weighted due date assignment substantially improves overall performance. It is very reasonable to penalize all of weighted earliness, tardiness and due date related costs.

Appendix A: Due-Date Assignment Rules

- WNOPPT (Weighted Number of operations plus Processing Times) → $Due = w1 \times k1 \times TPT + w2 \times k2 \times NOP$ ($w1$, $w2$ changes according to the weights)
- RDM (Random due assign.) → $Due = N\sim\left(3 \times P_{avg}, \left(P_{avg}\right)^2\right)$

- TPT = Total processing time
- P_{avg} = Mean processing time of all job waiting

Appendix B: Dispatching Rules

WATC/ATC ((Weighted) Apparent Tardiness Cost): This is composite dispatching rule, and it is a hybrid of MS and SPT and takes into account importance of customers.

WMS/MS: (Weighted) Minimum Slack First

WSPT/SPT: (Weighted) Shortest Processing Time First

WLPT/LPT: (Weighted) Longest Processing Time First

WSOT/SOT: (Weighted) Shortest Operation Time First

WLOT/LOT: (Weighted) Longest Operation Time First

WEDD/EDD: (Weighted) Earliest Due-Date First

WERD/ERD: (Weighted) Earliest Release Date First

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

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