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PROCESS PLANNING AND SCHEDULING WITH PPW DUE-DATE ASSIGNMENT USING HYBRID SEARCH

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Abstract

Although IPPS (Integrated Process Planning and Scheduling), and SWDDA (Scheduling With Due Date Assignment) are two popular area in which numerous work done, IPPSDDA (Integrated Process Planning, Scheduling And Due Date Assignment) is a new research field

only a few works are done. Most of the works assign common due dates for the jobs but this study assign unique due date for each job in a job shop environment. Three terms are used at the performance measure which is weighted tardiness, earliness and due dates. Sum of all these terms are tried to be minimized. Different level of integration of these three functions is tested. Since job shop scheduling is alone NP-Hard, integrated solution is harder to solve that's why hybrid search and random search are used as solution techniques. Integration found useful and as integration level increased solution is found better. Search results are compared with ordinary solutions and searches are found useful and hybrid search outperformed random search.

Keywords

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

1. Introduction

Process planning, Scheduling and due date assignment are three important functions that should be integrated. Conventionally these three functions are performed separately. But high interdependence between these three functions makes us to consider integration. Since outputs of upstream functions become inputs to the downstream functions we should handle upstream functions well and integrated with downstream functions.

In short we should integrate these three functions to increase global performance we obtained. As we integrated more functions the problem becomes more complex but global performance becomes better. Integration improves shop floor loading and we get better balanced shop floor loading. Alternative process plans provide us opportunity to choose from and in case of unexpected occurrences and to obtain better balanced shop floor loading we may chose other alternative routes. If due date assignment is integrated with other functions we can give more reasonable due dates that improves performance of the problem and reduce penalty function.

If we consider only scheduling problem, it belongs to NP-Hard class problem and integrated solutions are even harder to solve. For this reason exact solutions are only possible for very small problems. That is why for larger scale problems we should use some practical

methods that find a good solution instead of exact solution. At the literature some heuristics are used to find a good solution in a reasonable amount of time. In this search we applied hybrid

search and random search to find a good solution in a reasonable amount of time. At the hybrid search we started with random search and continued with genetic search. Since marginal benefit of random search is very high at the beginning but later marginal benefit gets smaller, we used random search at the beginning. Genetic search uses previous best results and random search does not use earlier results and every time it produces brand new solutions that is why genetic search is more powerful and we continued with genetic search.

If we define and give some more information about the functions respectively; 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 & Mallur, 1994) defined production scheduling as a resource allocator which considers timing information while allocating resources to the tasks. According to (Gordon, Proth & Chu, 2002) “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”

In this study we used RDM (Random) and PPW (Process Plus Wait) as due date determination rules. RDM is used for external due date assignment and PPW is used for internal due date assignment.

If we make a survey on literature on penalty functions, some researches penalized only tardiness, some works penalized both tardiness and earliness, some penalized number of tardy jobs and some of them penalized additionally manufacturing costs etc. In this research we penalized all of weighted earliness, tardiness and due date related costs.

2. Background and Related Researches

Conventionally process planning, scheduling and due date assignments are performed sequentially but high interdependence among these three function forces us to consider integration. There are numerous works on IPPS and SWDDA problems but there are only a few works on IPSDDA problem.

For the IPPS problem it is better to see (Tan & Khosnevis, 2000), and (Phanden, Jain & Verma, 2011) as surveys on IPPS problem.

Although it is better to have alternative process plans, Marginal benefits of alternative process plans diminish sharply and alternative process plans makes problem more complex so we should determine optimum number of alternative process plans we should select a plan among alternatives wisely, (Usher, 2003).

As we said, as alternative plans increases it becomes more complex to select the plan. (Ming & Mak, 2000) studied process plan selection problem by using a hybrid Hopfield network- genetic algorithm. (Bhaskaran, 1990) studied process plan selection in his study.

Developments in hardware, software and algorithm provide us to prepare process plans easier and as a result CAPP (Computer Aided Process Planning) is developed. (Aldakhilallah & Ramesh, 1999), and (Kumar & Rajoita, 2003) studied integration of process planning with CAPP.

Since only scheduling problem is NP-Hard problem and integrated problems are harder to solve, many researchers used genetic or evolutionary algorithms while solving the problem. (Morad & Zalzal, 1999), (Drstvensek & Balic, 2003), (Zhang & Wong, 2015).

For the early works it is better to check (Zhang & Mallur, 1994), (Brandimarte, 1999), (Kim & Egbelu, 1999) and (Morad & Zalzal, 1999) as earlier samples on IPPS.

For the most recent works on IPPS we can give following list as some sample on IPPS; (Tan & Khosnevis, 2000), (Usher, 2003), (Kumar & Rajotia, 2003), (Phanden et al, 2011), (Li, Gao & Li, 2012), (Seker, Erol & Botsali, 2013), (Wang, Fan, Zhang, & Wan, 2014), (Zhang & Wong, 2015) are the most recent examples.

As (Demir, Uygun, Cil, Ipek & Sari, 2015) mentioned, 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 sub problems.

Another popular research topic which may be related with this research is SWDDA problem. There is numerous works on SWDDA problem. Before studying this problem it is better to see a good survey on SWDDA that is made by (Gordon et al, 2002).

Due dates are determined internally and externally. In this study we both used RDM and PPW due date assignment rules. We integrated process plan selection with 21 dispatching rules and PPW due date assignment rule. 21 dispatching rules are determined according to the popular dispatching rules and weights of the jobs and multipliers. Due date determination rules are determined according to the multipliers and PPW takes one of nine values.

Conventionally only tardiness is punished, but according to JIT environment both earliness and tardiness is punished. Meanwhile in this research we penalized all of weighted earliness and tardiness and due date related costs. Since nobody wants far due dates we penalized due dates also.

In this research we studied m machines, n jobs with separate due date assignment job shop scheduling problem. But at the literature many works are on SMSWDDA (Single Machine Scheduling with Due Date Assignment) problem and some other problems are on MMSWDDA (Multiple Machine Scheduling with Due Date Assignment) problems. Although many works are on common due date assignment problem, in this study we assigned separate due dates for every jobs. For example jobs waiting to be assembled should be assigned common due date.

There are numerous works on SMSWDDA and (Gordon & Kubiak, 1998), (Biskup & Jahnke, 2001), (Wang, 2006), (Lin, Chou & Chen, 2007), and (Li, Yuan, Lee & Xu, 2011) are some examples to this type of problem.

Also there are numerous works on MMSWDDA problem. (Cheng & Kovalyov, 1999), and (Lauff & Werner, 2004) are some examples to this type of problem.

Although there are numerous works on IPPS and SWDDA problems, there are only a few works on integration of these three functions. If we give some works on IPPSDDA problem; (Demir & Taskin, 2005), (Demir, Taskin & Cakar, 2004), (Ceven & Demir, 2007) studied this new problem.

(Li, Ng & Yuan, 2011) studied single machine scheduling of deteriorating jobs with CON/SLK due date assignment. At this study they assumed actual processing time of a job is a linear increasing function of its starting time. They used CON (Common due date) and SLK (Equal slack) methods while determining due dates. They considered the problem of determining optimum due dates and processing sequence concurrently to minimize costs of earliness, due date assignment and weighted number of tardy jobs.

(Vinod & Sridharan, 2011) studied due date assignment rules and scheduling methods in a dynamic job shop environment. As a due date assignment method they used PWW, TWK, DTWK (Dynamic Total Work Content), RWK (Random Work Content) and as a scheduling rules they used seven different types of rules. System performance is calculated according to flow time and tardiness of the jobs.

(Yin, Cheng, Xu & Wu, 2012) studied single machine batch delivery scheduling and common due date assignment problem. Here while they are determining job sequence, common due date and job delivery scheduling, they are also considering option of performing a rate modifying activity on the machine. In this study they aimed to determine common due date for the jobs, location of the rate modifying activity and delivery date of the each job to minimize the sum of earliness, tardiness, holding, due date and delivery cost.

(Yin, Cheng, Yang & Wu, 2015) studied two-agent single-machine scheduling with unrestricted due date assignment problem.

3. Problem Definition

Three important manufacturing functions, process planning, scheduling and due date assignment are tried to be integrated using random-genetic hybrid search. Classically three functions are treated sequentially and separately but high interdependence between these three functions makes us strongly to consider integration. If we perform process planning and scheduling sequentially then process planners select most desired machines repeatedly and this cause unbalanced machine loading and in case of unexpected occurrences and to balance shop floor loading we may not change process plans at shop floor level and this cause inferior shop floor performance and cause unbalanced machine loading where some machines become bottleneck and some starves and utilization of these resources may be very low. If we perform due date assignment separately then we may give unreasonably close due dates and we cannot keep our promise and this cause customer ill will or we may give long due dates and this increases penalty functions. By integrating due date assignment with other functions we may give reasonable due dates which are neither too early or nor too late. So we can keep our promise

better and we can improve performance measure greatly. Sum of total weighted earliness, tardiness and due date related costs become minimum by integrating these three functions.

Although at the literature IPPS problem and SWDDA problems are studied extensively, integration of these three functions is very new research topic and in this study we tried to integrate all of these three functions by using random-genetic hybrid search.

In this study we have alternative routes and select one of these alternatives and we have 21 dispatching rules and we select best suitable scheduling rule and we select best parameters for PPW due date assignment rule. We use hybrid search and random search in solution and compare search techniques with each other and with ordinary solutions. Problem is represented as chromosomes as in explained in Figure 1 at the section 4.

By applying hybrid search and random search we tried to find better route, better scheduling rule and better due date assignment rule that gives better performance.

We have three shop floors to solve. These shops are small, medium and large shop floors. Characteristics of these shop floors are summarized at Table 1 below. If we explain small shop floor, there are 20 machines, 50 jobs to be scheduled and each job has 5 alternative routes and each route has 10 operations. Processing times of the operations are distributed randomly in between 1 and 30 according to normal distribution with mean 12 and standard deviation 6 according to formula $[(12 + z * 6)]$.

At this research we assumed a day 480 minutes. If there is a shift per day then $8*60$ makes 480 minutes. We penalized weighted earliness, tardiness and due date related costs. Penalty function terms are given and explained at the next page.

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	$[(12 + z * 6)]$	$[(12 + z * 6)]$	$[(12 + z * 6)]$
# of op. per job	10	10	10

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

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

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

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

$$\text{Total Penalty} = \sum_j \text{Penalty}(j) \quad (5)$$

Where $\text{weight}(j)$ is the weight of job j . D is the due date, E is the earliness and T is the tardiness of job j . $P.D(j)$ is penalty for due date, $P.E(j)$ is the penalty for earliness and $P.T(j)$ is the Penalty for tardiness of job j . $\text{Penalty}(j)$ is the total penalty for job j . Finally by using (5) we determine Total Penalty which is the total penalty for all of the jobs.

4. Solution Techniques Used

Two search techniques are used which are hybrid search and random search. We compared search results with each other and with ordinary solutions. Marginal benefits of random search are high at the beginning but it decreases fast as iteration goes on. That's why we thought hybrid search is a powerful search technique. We started random search and continued with genetic search. If we explain solution techniques in detail as below;

Ordinary Solutions: Here we used initially produced three populations with 23 chromosomes. A starting population with 10 chromosomes instead of main population, a population with 8 chromosomes instead of crossover population and a population with 5 chromosomes instead of mutation population. Best 10 chromosomes out of 23 chromosomes are selected as the initial step main population. We used these chromosomes of this produced initial step main population as the ordinary solutions. We did not apply any random or genetic iteration over this initial main population yet.

Random Search: With this technique we applied 200, 100 and 50 random iterations for the shop floors respectively. We use three populations, a population with size 10 as main population, a population with size 8 as great as crossover population and a population with size 5 as big as mutation population. This is because we wanted to be fair in comparison of random search and genetic search. At every genetic iteration we produce new crossover population with size 8 and we produce new mutation population with size 5 by using genetic operators. But at random search we produced these many chromosomes for two similar populations randomly. At

every iteration we uses previous step main population and newly randomly produced crossover and mutation population. By using best ten chromosomes of these three populations we produce new main population of the current iteration.

Hybrid search: At this search we started with random search and continued with genetic search. We applied totally 200, 100 and 50 iterations as in random search to be fair in comparison. Initial iterations were random and after that we continued with genetic iterations and iteration parameters are given in Table 4. Genetic search uses best results obtained so far to get better solutions that are why it is called directed search. Random search produce brand new solutions at every step and does not use previous iterations results and that's why it is called undirected search. So genetic search is expected to be more powerful but at the initial iterations random search provide high marginal improvements. If we combine these two search techniques then we can get benefit of these two techniques. That's why we started with random search with high marginal improvement and we continued with genetic iterations when marginal benefit of random search is low and benefit of directed search is high.

Below at Figure 1 a sample chromosome is illustrated. There are $(n+2)$ genes in every chromosome. First two genes are used for due date assignment rules and dispatching rules respectively. Remaining n genes are used to represent selected routes of each job. At the small and medium shop floors we used 5 alternative routes and at the large shop floor we used 3 alternative routes to reduce computational times and reduce memory requirements. In fact alternative routes are very useful at the beginning, but marginal benefit of alternative routes sharply diminishes.

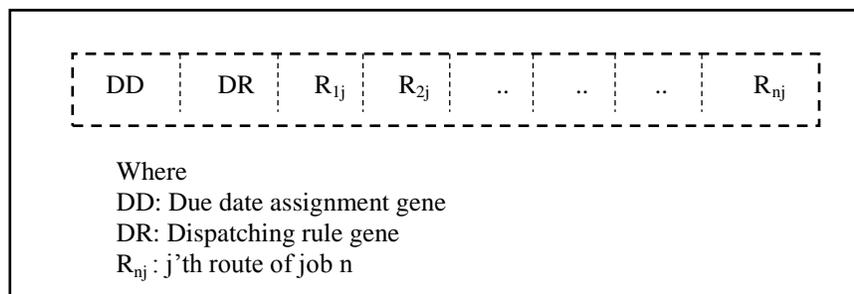


Figure 1: Sample chromosome.

We used mainly two rules while assigning due dates. PPW and RDM due date assignment rules are used. With different multipliers and constants PPW takes one of nine different values. With the RDM rule first gene of each chromosome takes one of ten different values. These rules are given at Table 2 below.

Table 2 Due-Date Assignment Rules

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

Second gene of the chromosome assumes one of twenty one different values. Mainly we used nine dispatching rules and considering weights and multipliers second gene takes one of twenty one values. Dispatching rules are summarized at Table 3.

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

5. Compared Solutions

At this research we compared ordinary solutions with search results and searches are compared with each other. Different integration levels are tested. For every integration level ordinary solutions and hybrid search solutions are recorded. Since full integration level is the best combination we also tested random search for this combination.

Solutions according to different integration level for hybrid search are explained below. At the hybrid search initial iterations are random iterations and later we continued with genetic iterations. Iteration parameters are given at Table 4.

SIRO-RDM (Hybrid): Here all functions are disintegrated. Process plan selection is independent from scheduling and due date assignment. Jobs are dispatched in random order and due dates are determined randomly.

SCH-RDM (Hybrid): Later we integrated scheduling function with process plan selection but due dates are still determined randomly. We observed substantial improvements at the performance measure by this integration.

SIRO-PPW (Hybrid): This time we integrated PPW due date assignment with process plan selection but jobs are scheduled in random order. Although there is a substantial improvements with this integration, SIRO rules strictly deteriorates the performance measure back.

SCH-PPW (Hybrid): At this level of integration three functions are integrated. Process plan selection is integrated with scheduling and PPW due date assignment rule. By full integration we observed substantial improvement and we obtained best performance measure. Since this is the best combination we tested random search for this level of integration and as it is expected genetic search outperformed random search. In short full integration level with genetic search is found as the best combination.

Table 4 Iteration Parameters

	Shop Floor1		Shop Floor2		Shop Floor3	
	<i>Rnd. Iter. #</i>	<i>Genetic Iter. #</i>	<i>Rnd. Iter. #</i>	<i>Genetic Iter.#</i>	<i>Rnd. Iter. #</i>	<i>Genetic Iter. #</i>
Random Search	200	-	100	-	50	-
Hybrid Search	50	150	25	75	15	35
Cpu time Aprox.	200 sec		500 sec		1000 sec	

6. Experiments and Results

C++ programming language is used while coding the program. We used a laptop with 2 GHz processor and 8 GB Ram while running the program. Operating system was windows 8.1 and Borland C++ 5.02 Compiler is used. While all programs are open at the background, CPU times to run the program written in C++ are recorded and given at Table 5, 6 and 7.

Three shop floors are tested for different level of integration and with different techniques. Nine types of solutions are compared according to different integration level and

search techniques. First four solutions were ordinary solutions and these results are obtained from the best ten chromosomes of initially randomly produced populations. Next four solutions are the results of hybrid search results according to the different level of integration. Finally best integration level is solved also by using random search.

At the beginning we tested unintegrated combination and tested SIRO-RDM (Hybrid) and SIRO-RDM (Ordinary) combinations. Here process plan selection, scheduling due date assignment are all disintegrated. After that we integrated scheduling with process plan selection but due dates are still determined randomly. At this level we tested SCH -RDM (Hybrid) and SCH-RDM (Ordinary) combinations. Later we integrated PPW due date assignment with process plan selection but this time dispatching is unintegrated and jobs are scheduled in random order. Although this integration substantially improves the solution, SIRO rule strictly deteriorates the performance back. At this step we tested SIRO-PPW (Hybrid) and SIRO- PPW (Ordinary) combinations. At the end we tested full integration level and this level is found the best combination. Since this is the best combination we also used random search in addition to the hybrid search. We found full integration with hybrid search as the best combination and at this level we tested SCH- PPW (Hybrid), SCH- PPW (Random), and SCH- PPW (Ordinary) combinations. Results of ordinary solutions are only shown for small shop floor and similar results are obtained for medium and large shop floors.

For small shop floors we used 200 random or genetic iterations and combinations of iterations are summarized at Table 4. CPU times of small shop floor are listed at Table 5 below. Program run took 100 to 250 seconds approximately. According to the results, integration levels are found useful, SIRO dispatching rule and RDM due date assignment found very poor and full integration with hybrid search found the best combination. Hybrid search outperformed random search and ordinary solutions found very poor.

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-PPW(O)	512,91	459,51	394,63	-
SCH-PPW (O)	482,33	404,94	371,2	-

-	-	-	-	-
SIRO-RDM(H)	403,17	401,17	396,24	114 sec
SCH-RDM(H)	353,65	353,24	352,34	215 sec
SIRO-PPW(H)	352,23	350	343,26	240 sec
SCH-PPW (H)	328,16	326,98	325,19	114 sec
SCH-PPW (R)	354,99	352,46	348,08	122 sec

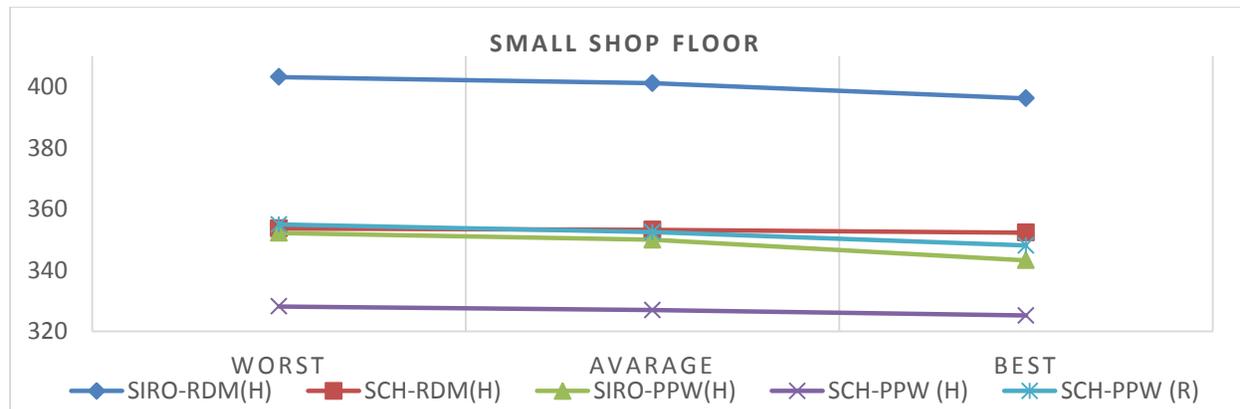


Figure 2: *Small shop floor results*

For the medium shop floor similar results are obtained. CPU times to finish the program were approximately in between 300 to 500 seconds. We performed 100 random or genetic iterations. Full integration level with hybrid search is found the best combination. Searches are always found better than ordinary solutions and hybrid search outperformed random search.

Table 6 *Comparison of Nine Types of Solutions for Medium Shop Floor*

	Worst	Average	Best	Cpu Time
SIRO-RDM(H)	983,48	976,4	964,51	294 sec
SCH-RDM(H)	797,79	793,96	790,96	534 sec
SIRO-PPW(H)	907,1	905,72	902,47	386 sec
SCH-PPW (H)	835,63	833,92	830,98	364 sec
SCH-PPW (R)	872,17	865,56	858,17	379 sec

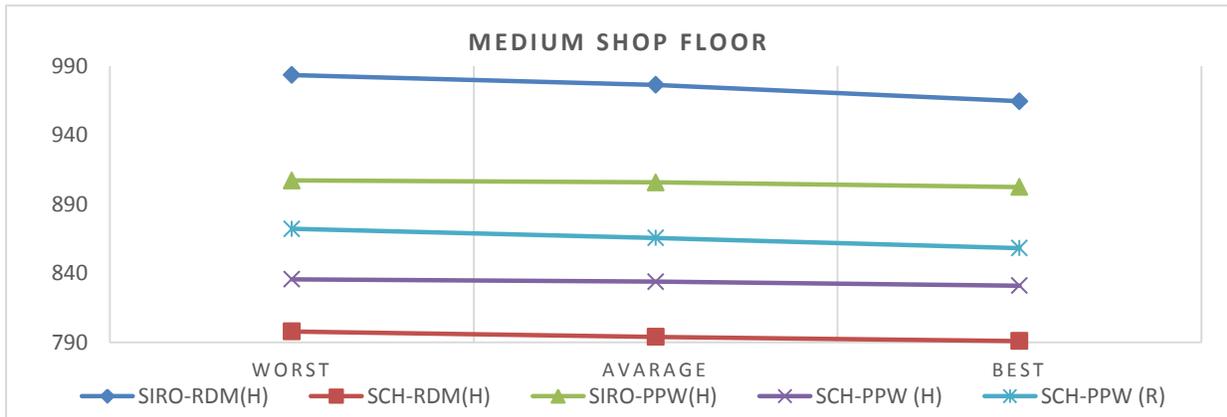


Figure 3: Medium shop floor results

Largest shop floor was the third shop floor with 40 machines and 200 jobs. Similar results are found as in previous shop floors. We applied 50 random or genetic iterations with the combinations specified at Table 4. To finish 50 iterations took approximately 600 to 800 seconds. Results of shop floor 3 are summarized at Table 7 and Figure 4. From the results we can see that ordinary solutions are the poorest solutions. Searches are found useful and hybrid search outperformed random search. Full integration with hybrid search found the best combination.

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

	Worst	Average	Best	Cpu Time
SIRO-RDM(H)	2528,85	2515,24	2495,2	669 sec
SCH-RDM(H)	2024,63	2020,64	2012,93	753 sec
SIRO-PPW(H)	2290,53	2281,93	2267,66	773 sec
SCH-PPW (H)	1963,96	1960,22	1953,53	746 sec
SCH-PPW (R)	2044,32	2032,17	2012,63	743 sec

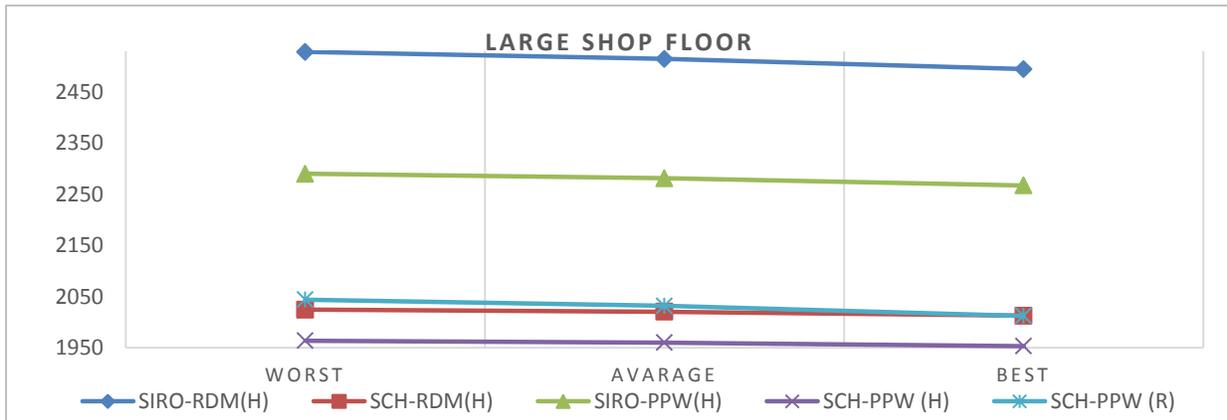


Figure 4: Large shop floor results

7. Conclusion

Although at the literature there are numerous works on IPPS and SWDDA problems, there are only a few works on IPPSDDA problem. We tried to integrate three important functions which are process planning, scheduling and due date determination. We tried to integrate these functions step by step and observed the results. We also compared hybrid search and random search with each other and with ordinary solutions.

We have shown that integration level improves the performance. Disintegrated combination gives the poorest result. Since each functions tries to get local optima, disintegrated combination deteriorates the global optima. Also these three functions highly effects each other , that's why we should be careful while performing any one of these functions and should integrate them and perform them concurrently. For example if process planning is performed separately then process planners may select same desired machines repeatedly and may not select some undesired machines at all. This cause unbalanced machine load at the shop floor level and reduce shop floor utilization. Similarly if we disintegrate due date assignment from scheduling then we may assign unnecessarily far due dates and this time earliness and due date related costs increase. If we assign unrealistically close due dates then we may not keep our promise and damage our reputation and tardiness costs substantially increase. If scheduling is unintegrated then we may schedule jobs with close due dates later or vice versa.

Conventionally tardiness is punished but according to JIT both earliness and tardiness should be punished. At this research we penalized all weighted earliness, tardiness and due date

related costs. Since nobody wants far due dates it is better to penalize due date related costs also. Due date related costs are customer ill will, customer loss, price reduction etc.

As a summary, it is better to integrate all of these three functions and we should use hybrid search instead of random search. At the beginning marginal benefit of random search is high so it is good to use random search, but later marginal benefit of random search strictly diminishes it is better to change into genetic search. So hybrid search utilize advantage of both random search and genetic search. It is very reasonable to penalize all weighted earliness, tardiness and due date related costs.

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