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Solving process planning and weighted scheduling with WNOPPT weighted due-date assignment problem using some pure and hybrid meta-heuristics

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ABSTRACT

If we search literature for integrated process planning and scheduling problem and for scheduling with due date assignment problem we can find hundreds of researches made on these problems. But integration of the three important manufacturing functions are not addressed much in the literature. In this study process planning, weighted scheduling and weighted due date assignment functions are integrated and solved using some pure and hybrid metaheuristics. We studied eight shop floors using random, evolutionary strategies, genetic algorithms and some hybrid searches. We tried to observe how search techniques improve solutions as iterations go on and how evolutionary strategies, genetic algorithms and hybrid search performs well compared to the random search. We also observed that hybrid searches are also powerful search techniques as genetic search and evolutionary strategies.

Keywords: process planning, weighted scheduling, weighted due date assignment, evolutionary strategies, genetic algorithm, hybrid metaheuristics, random search

Proses planlama ve ağırlıklı teslim tarihi atama ile birlikte ağırlıklı çizelgeleme probleminin bazı saf ve melez meta-sezgisel yöntemler ile çözümü

ÖZ

Entegre süreç planlama ve çizelgeleme probleminin ve entegre teslim tarihi atama ile birlikte çizelgeleme probleminin literatürüne baktığımızda, literatürde bu konularda yüzlerce araştırma bulabiliriz. Fakat, üç önemli üretim fonksiyonlarının entegrasyonu konusu literatürde ele alınmayan bir alandır. Bu çalışmada süreç planlama, ağırlıklı çizelgeleme ve ağırlıklı teslim tarihi atama fonksiyonları entegre edilmiş ve problem bazı saf ve melez meta-sezgisel yöntemler kullanılarak çözülmüştür. Bu çalışmada biz 8 farklı atölyeyi rassal, evrimsel stratejiler, genetic algoritmalar ve bazı melez aramaları kullanarak çalıştık. Biz arama yöntemlerinin çözümü iterasyonlar devam ederken nasıl iyileştirdiğini ve evrimsel stratejiler, genetic algoritmalar ve melez aramaların rassal aramalara göre daha üstün sonuçlar verdiğini gözlemledik. Ayrıca melez aramaların genetic arama ve evrimsel stratejiler gibi güçlü arama teknikleri olduğunu gözlemledik.

Anahtar Kelimeler: süreç planlama, ağırlıklı planlama, ağırlıklı teslim tarihi atama, evrimsel stratejiler, genetik algoritma, melez meta-sezgiseller, rassal arama

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1. INTRODUCTION

When we look at the literature hundreds of works on IPPS (Integrated process planning and scheduling), many works on SWDDA (Scheduling with due date assignment) can be found easily. But when we look at the literature for IPPSDDA (Integrated process planning, scheduling and due date assignment) we can see only a few works on this problem.

Since only scheduling problem belongs to NP-Hard class problem and integrated problem is even more complex many researchers use some heuristics in the solution of the problem. In this study random search, genetic search and random-genetic hybrid search, evolutionary strategies, hybrid random-evolutionary strategies are used as solution techniques.

Since upstream functions affect downstream functions we should consider three functions concurrently. For instance outputs of process planning becomes inputs to the scheduling problem. Poorly prepared process plans become poor inputs to the scheduling function and may not be followed at the shop floor level. When these two functions are independent then they try to get local optima and do not care about global optima. Process planners may select same desired machines repeatedly and may not select some undesired machines and this cause unbalanced machine loading at the shop floor level. If due-dates are assigned independently then we may determine too close or too far due dates and this cause high penalty costs. If we assign due dates concurrently then we may set realistic due dates neither too close nor too far due dates and we may reduce earliness, tardiness and due date related costs. If scheduling is performed independently from assigned due-dates then we may schedule some jobs unnecessarily too early and we pay high earliness costs and if we schedule some jobs unreasonably too far then we pay for high tardiness costs.

In this study we used genetic search and evolutionary strategies as directed searches, random search as undirected search and random-genetic and random-evolutionary strategies as hybrid undirected-directed searches while solving the problem. Random search is a good way to scan solution space faster at the beginning but it becomes inferior search technique as iteration goes on. It is because random search does not get benefit of previously found good solutions and that’s why it is an undirected search. Genetic search and evolutionary strategies get use of earlier good solutions and that’s why they are directed searches but at the initial few iterations random search scans solution space better compared to the genetic search and evolutionary strategies. At this research we used both the powers of random and genetic searches and evolutionary strategies and we applied hybrid searches. At hybrid searches %10 of the iterations are random and later we converted to the genetic search or evolutionary strategies and remaining %90 percent iterations are genetic iterations or evolutionary strategy iterations.

Recent developments in hardware, software and algorithms provided to solve some problems easier compared to the past and even some unsolvable problems became possible to solve. It is easier to prepare alternative process plans using CAPP (Computer aided process planning) and it becomes easier and beneficial to integrate process planning, weighted scheduling and weighted due-date assignment.

Traditionally only tardiness is punished but according to JIT (Just in time) philosophy jobs are not wanted to be finished earlier or later then its due-date. In this research we penalized all of the due-dates, earliness and tardiness according to the importance of the customer. Contrary to literature here we applied weighted due-date assignment and important customers are given closer due dates and later these customers are scheduled earlier by using weighted scheduling. By doing this we reduced penalty of due dates, penalty of tardiness and earliness for more important customers and we substantially saved from total penalty function.

Here we used five alternative routes for relatively smaller shops and three alternative routes for relatively bigger shops. We applied weighted scheduling and 21 dispatching rules are used. Finally we used WNOPPT (Weighted number of operations plus processing time) weighted due date assignment method while determining due dates.

2. BACKGROUND AND LITERATURE SURVEY

Although there are only a few study on IPPSDDA problem there are numerous work on IPPS problem and many works on SWDDA problem. As IPPS and SWDDA problems are popular research topics IPPSDDA problem is also promising research area and many more researches can be done.

It is better to see some surveys on IPPS before going into detail. we can see [1], [2] and [3] as a good literature surveys on IPPS problem.

Although alternative process plans are important in IPPS and IPPSDDA problems, it is better to determine number of process plans wisely. Since marginal benefits of alternative process plans are diminishing, there is a turning point in the number of efficient number of alternative process plans. In this context impacts of alternative process plans on manufacturing performance is studied by Usher [4] and availability and their effects on manufacturing system performance of alternative process plans are studied by Corti and Portioli-Staudacher [5].

As we sad developments in hardware, software and algorithms make it possible to solve some problems easier and development in CAPP made IPPS and IPPSDDA problems easier compared to the past. Usher and Fernandes [6], Aldakhilallah and Ramesh [7], and Kumar and Rajoita [8] studied integration of CAPP and scheduling.

Because only scheduling belongs to NP-Hard class problem, researchers used some metaheuristics to solve the problem. Genetic or evolutionary algorithms are widely used in solving IPPS. Morad and Zalzala [9], Zhao and Wu [10], Moon et al. [11], Kim et al. [12], Drstvensek and Balic , Moon et al. [13], Shao et al. [14], Li et al. [15], Li et al[16], Seker et al. [17], and Zhang and Wong [18] are some examples on this area.

For couple of decades many researchers are working on IPPS and if we list some earlier works on IPPS ; Wilhelm and Shin [19], Sundaram and Fu [20], Nasr and Elsayed [21], Khoshnevis and Chen [22], Hutchinson et al. [23], Chen and Khoshnevis [24], Zhang and Mallur [25], Kempenears et al. [26], Usher and Fernandes [6], Kim and Egbelu [27], Weintraub et al. [28], Morad and Zalzala [9], and Gindy et al. [29] are earlier examples on IPPS.

If we give some examples to more recent works on IPPS; Tan and Khoshnevis [1], Lee and Kim [30], Saygin et al. [31], Zhao and Wu [10], Moon et al. [11], Kim et al. [12], Kumar and Rajotia [32], Usher [4], Zhang et al. [33], Drstvensek and Balic [34], Corti and Portioli-Staudacher [5], Moon et al. [13], Shao et al. [14], Ozguven et al. [35], Phanden et al. [36], Yin et al. [37], Yin et al. [37], Seker et al. [17], Wang et al. [38], Zhang and Wong [18] are some recent examples on this area.

It is seen that solving integrated problems are harder according to the literature. There is a solution only for small problems. Some meta-heuristic algorithms like genetic, evolutionary or agent based, have been utilized to solve the IPPS problem. Researchers divided the problem into two subproblems which are loading and scheduling subproblems [39].

SWDDA is also very popular research topic. Hundreds of works done on SWDDA problem. Due-dates can be determines as internally or externally. If we can set due-dates internally then firms may select most proper due-dates for them. If we integrate scheduling with due-date assignment then we may set more proper due dates and integrated scheduling also increases the performance and we may reach reduced penalty function. For SWDDA problem it is better to see Gordon et al. [40] as a state-of-the-art review. Traditionally only tardiness is punished but according to JIT both earliness and tardiness should be punished and in this study all of earliness, tardiness and due-dates are penalized according to weight of the customers. In this study as a weighted due-date assignment method WNOPPT is used.

Many works in literature are on scheduling with common due date assignment. Unlike these works in this study separate due dates are assigned for every jobs. If we give some list on scheduling with common due date we can give following list; Biskup and Jahnke [41], Cheng et al.[42], Gordon et al. [43], Lauff and Werner [44], Min and Cheng [45], Gordon and Strusevich [46], Allaoua and Osmane [47], Tuong and Soukhal [48], Yin et al. [37].

If we give some list on scheduling and separate due date assignment; Gordon and Kubiak [49], Cheng and Kovalyov [50], Gupta et al. [51], Baykasoğlu et al. [52], Xia et al. [53], Gordon and Strusevich [46], Vinod and Sridharan [54].

If we look at literature there are many works on single machine scheduling with due date determination. These works can be listed as follows; Kovalyov [55], Gordon and Strusevich [46], Cheng et al. [56], Qi et al. [57], Gordon et al. [43], Li et al. [58], Xia et al. [53], Allaoua and Osmane [47], Tuong and Soukhal [48].

Some works are on two machine flow shop scheduling with due date determination such as Birman and Mosheiov [59].

Some works are on parallel machine scheduling with due date determination as follows; Adamopoulos and Pappis [60], Cheng and Kovalyov [50], Mosheiov [59], Gordon et al. [43], Min and Cheng [45], Mosheiov and Yovel [61], Tuong and Soukhal [48].

Some works are on multi machine scheduling with due date determination as follows Luss and Rosenwein [62], Lawrance [63], Gupta et al. [51], Lauff and Werner [44]. Some works are on job shop scheduling with due date determination such as; Yang, He et. al. [64], Baykasoğlu et al. [52], Vinod and Sridharan [54].

As we mentioned earlier there are only a few works on IPPSDDA problem. Demir and Taskin [65] studied IPPSDDA problem in a Ph.D. thesis. Later benefits of integrating due date assignment with IPPS is studied by Ceven and Demir [66] in a Master of Science thesis. Later Demir et al. [39] studied Process planning and scheduling with SLK due-date assignment . After that Demir et al. [67] worked on Integrating Process Planning, WMS Dispatching, and WPPW Weighted Due Date Assignment where process planning and weighted scheduling and weighted due date assignments are integrated. Unlike literature in this study important customers are given closer due-dates and scheduled earlier. At the same time Demir et al. [68] investigated Process Planning and Weighted Scheduling with WNOPPT Weighted Due-Date Assignment problem. Finally Demir et al. [69]studied Process Planning and Scheduling with PPW Due-Date Assignment Using Hybrid Search.

3. PROBLEM DEFINITION

In this research IPPSDDA problem is investigated and process planning function is integrated with weighted scheduling and WNOPPT weighted due date assignment. Eight shop floors are tested in this study. Configurations of these shop floors are summarized at Table 1.

Table 1. Shop Floors

Shop floor	#of jobs	#of machines	#of routes	# of op. per job	Processing times
Shop floor 1	25	5	5	10	$\lfloor(12 + z * 6)\rfloor$
Shop floor 2	50	10	5	10	$\lfloor(12 + z * 6)\rfloor$
Shop floor 3	75	15	5	10	$\lfloor(12 + z * 6)\rfloor$
Shop floor 4	100	20	5	10	$\lfloor(12 + z * 6)\rfloor$
Shop floor 5	125	25	3	10	$\lfloor(12 + z * 6)\rfloor$
Shop floor 6	150	30	3	10	$\lfloor(12 + z * 6)\rfloor$
Shop floor 7	175	35	3	10	$\lfloor(12 + z * 6)\rfloor$
Shop floor 8	200	40	3	10	$\lfloor(12 + z * 6)\rfloor$

If we explain shop floor 1; there are 25 jobs, 5 machines, 5 alternative routes for every job and there are 10 operations in every route of each job. Processing times of every operation changes according to the formula $\lfloor(12 + z * 6)\rfloor$ and practically operation times changes in between 1 and 30 and assume nearest smallest integer to the value we obtained according to the above formula.

4. RULES AND FORMULAE

In this study, contrary to literature all of weighted earliness, tardiness and due date related costs are penalized. We assumed here one shift and it makes 8*60=480 minutes per day. Penalty function terms for weighted earliness, tardiness and due dates are summarized below.

$$\mathrm{PD(j)} = \mathrm{weight\ (j)} * 8 * \left(\frac{\mathrm{D}}{480}\right) \quad (1)$$

$$\mathrm{PE(j)} = \mathrm{weight\ (j)} * \left(5 + 4 * \left(\frac{\mathrm{E}}{480}\right)\right) \quad (2)$$

$$\mathrm{PT(j)} = \mathrm{weight\ (j)} * \left(10 + 12 * \left(\frac{\mathrm{T}}{480}\right)\right) \quad (3)$$

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

$$\mathrm{Total\ Penalty} = \sum_{\mathrm{j}} \mathrm{Penalty(j)} \quad (5)$$

where
weight(j) is the importance of customer j
PD(j) is the penalty for due-date of job j
PE(j) is the penalty for earliness of job j
PT(j) is the penalty for tardiness of job j
Penalty (j) is the total penalty of job j that contains due date, earliness and tardiness related costs
Total Penalty is the total penalty occurred for all of the jobs

4.1. Due-Date Assignment Rules

At the due date assignment gene 10 rules are used with different multipliers. Nine rules are some derivatives of WNOPPT rule. Tenth rule represent random (external) due date assignment rule. Due date assignment rules are given 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

Where

- 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

4.2. Dispatching Rules

As a scheduling gene 21 dispatching rules (with weighted and unweighted versions of the rules) are used. Scheduling rules are summarized at Table 3.

Table 3. Dispatching Rules

Method	Multiplier	Rules
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

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

5. TECHNIQUES USED

In this research three search techniques and ordinary solutions are compared. As a directed search genetic search and evolutionary strategies are used, as an undirected search random search is used and finally as a hybrid undirected-directed search techniques hybrid random-genetic and random-evolutionary strategies are used. Every techniques are explained below;

Ordinary Solution(OS): At the genetic search three populations are used. Main population with size 10, crossover population with size 8 and mutation population with size 5. To be fair at random search we used same sizes of populations. To be fair again at hybrid search we used same sizes of iterations as in genetic and random search. As an ordinary solutions we first randomly produced three populations with size 10,8 and 5 respectively and we selected best 10 chromosomes out of 23 chromosomes as the starting main population. Results of starting main populations are used as ordinary solutions where we have not applied given number of iterations yet.

Random Search(RS): This is undirected search and at this search only random iterations are applied. At every iteration two populations are produced randomly instead of genetically as big as crossover and mutation populations. Out of three populations best ten chromosomes are selected as the next step main population and one iteration is completed like this.

Evolutionary Strategies (ES): In the early 1960s unlike genetic algorithms, evolutionary strategies are developed. Two students from Technical University of Berlin from Germany developed evolutionary strategies while solving their optimization problem [70], [71]. At the genetic algorithms we use crossover and mutation operators but here we only utilize mutation operator. At the genetic search, hybrid search and random search we produce 13 new offspring and apply some predetermined number of iterations. Here at the evolutionary strategies in order to be fair in comparison we apply same number of iterations for every shop floor and we produce 13 new offspring by using only mutation operator.

Hybrid Evolutionary Strategies (R-ES): This is a mix of undirected and directed search and get benefits of power of both random and evolutionary strategies. Random search initially scans solutions space better compared to the evolutionary strategies. Between 0 and 1000 if we produce a random number then expected value of this number is 500 and marginal improvement is 500. If we produce two random numbers and expected value of maximum of these two numbers is 667 and marginal benefits drop to 167. If we produce three random numbers and expected value of maximum of these three numbers is 750 and marginal benefit reduced to 83. As it can be seen random iterations are very useful at the initial iterations to scan solution space faster but as iteration goes on marginal benefit reduces sharply. Later directed search becomes more powerful compared to random search because evolutionary strategies get benefits of best solutions found so far but random search does not get benefits of earlier iterations and every time it starts from the scratch and as iteration goes on it improves with less probability. By using hybrid search initially we scan solution space faster and we start with better solutions and turn into evolutionary strategies and we get benefits of directed search.

Genetic Algorithm (GA): This search is directed search and at every iteration we look for better solutions around the best solutions found so far. At every iterations we select four pairs of chromosome from the main population and we produce crossover population with size 8. Later we select 5 chromosomes to be mutated and we produce mutation population with size 5. For crossover and mutation we select best chromosomes of the main population with high probability and we select worst chromosomes of the population with low probability proportional to the performance measure of the chromosomes.

Hybrid Genetic Algorithm(R-GA): Here search is started with random search to scan solution space better at the beginning and later genetic search is applied. At every search technique we produce 13 new offsprings and it was fair to compare these pure and hybrid searches. One important thing in hybrid search is the percentage of random search. If random search is very high then hybrid search becomes very poor since as iteration goes on marginal benefit of random search reduces sharply. If random search percentage is too low then we start to genetic search before we scanned solution space better. Here 10% random iterations are applied later genetic search is used.

Iteration parameters of each shop floor for pure and hybrid search metaheuristics are presented at Table 2.

At the search techniques we represented solutions as chromosomes and at every chromosome we have *(n+2)* genes. First gene is used for due date assignment and second gene is used for dispatching rules and remaining *n* genes are used to represent currently selected route of each job. A sample chromosome is illustrated at the Figure 1 below.

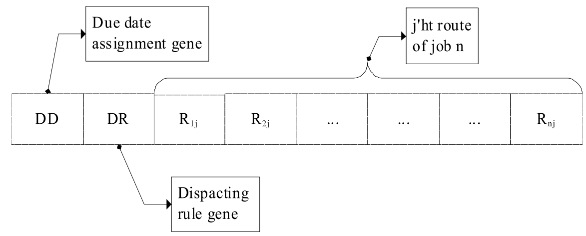

Figure 1. Sample chromosome

6. SOLUTIONS COMPARED

SIRO-RDM(OS, GA, R-GA, ES, R-ES, RS): In this study this is the lowest level of integration. Jobs are scheduled in random order and due dates are assigned randomly.

WSCH-RDM(OS, GA, R-GA, ES, R-ES, RS): At this level of integration weighted dispatching is integrated with process planning. Due dates are still determined randomly.

SIRO-WNOPPT(OS, GA, R-GA, ES, R-ES, RS): Here WNOPPT weighted due date assignment is integrated with process plan selection. But jobs are scheduled in random order.

WSCH-WNOPPT (OS, GA, R-GA, ES, R-ES, RS): This is the highest level of integration and weighted scheduling and WNOPPT weighted due date assignment are integrated with process plan selection. Ordinary solutions, genetic search, random search, hybrid searches and evolutionary strategies are compared. Number of random and genetic iterations are summarized at Table 4 below.

Table4. Iteration Numbers For Pure and Hybrid Searches

	ES	R-ES Hybrid		RS	GA	R-GA Hybrid	
Shop Floor	ES Iter#	Random Iter#	ES Iter#	Random Iter#	GA Iter#	Random Iter#	GA Iter #
1	200	20	180	200	200	20	180
2	150	15	135	150	150	15	135
3	100	10	90	100	100	10	90
4	50	5	45	50	50	5	45

In this study twenty four solutions are compared and four of them are ordinary solutions at every level of integration. Four of them are genetic search solutions at every level of integration, four of them are random-genetic search solutions, four of them are evolutionary strategies, four of them are random-evolutionary strategies and finally four of them are random search solutions.

7. EXPERIMENTS AND RESULTS

We used Borland C++ 5.02 as a compiler and we coded the program using C++ programming language. The program is run on a desktop with a processor i5-4590 with 3,3 GHz and 8 GB Ram.

Eight shop floors are tested with twenty four combinations possible. Initially SIRO-RDM(OS, GA, R-GA, ES, R-ES, RS) combinations at the lowest level of integration are tested. Later weighted scheduling is integrated with process plan selection and WSCH-RDM(OS, GA, R-GA, ES, R-ES, RS) combinations are tested. After this step WNOPPT weighted due date assignment is integrated with process plan selection but this time jobs are scheduled in random order and SIRO-WNOPPT(OS, GA, R-GA, ES, R-ES, RS) combinations are solved. Finally full integration level where process plan selection is integrated with weighted scheduling and WNOPPT weighted due date assignment is tested. At this level WSCH-WNOPPT (OS, GA, R-GA, ES, R-ES, RS) combinations are tried.

Experimental results of eight shop floors are summarized at Table 5 and Figures 2,3,4,5,6,7,8,9. For instance for the smallest shop floor we have 25 jobs and 5 machines and each job has 5 alternative routes. There are 10 operations at every route and processing time of each operation changes according to formula$\lfloor(12 + z * 6)\rfloor$. At each integration level 6 combinations are compared and there are 4 integration levels and we compared 24 combinations. For every shop floors we compared these 24 combinations and as expected full integration level (WSCH-WNOPPT) is found always best integration level and unintegrated level (SIRO-RDM) was found the poorest level of integration. Intermediate integration levels are also found useful. For instance integrating weighted scheduling with process plan selection (WSCH-RDM) also improved the global performance substantially but not as much as in full integration level. Although integrating weighted due date assignment with process plan selection (SIRO-WNOPPT) improved the global performance SIRO scheduling deteriorates the performance measures back severely. If we look at the results GA, R-GA, R-ES performed well and at the most of the shop floors GA algorithm outperformed other techniques. RS was the poorest method found. For the Shop floor 1,4,5,6,7 GA is the best search method, for the shop floors 2 and 3 R-ES is found as the best search method and for the shop floor 8 R-GA search method is found best. Hybrid solutions are also powerful solutions depending on the random search percentage. Here we used 10% random iterations. Random search is very useful at the beginning and benefit of random search diminishes sharply so it is better to use 5% or 10% random iterations but after that random iterations become very poor to use. Since GA or ES are directed search later it is better to convert to directed search techniques after some initial random iterations.

8. CONCLUSION

At this study integrated process planning and weighted scheduling with weighted due date assignment problem is studied. Problem is integrated step by step and improvement in global performance is observed.

At the beginning unintegrated version SIRO-RDM combinations are tested. Here due dates are assigned randomly and jobs are scheduled in random order and as expected this level of integration is found the poorest level. Later weighted scheduling function is integrated with process plan selection but due dates are still determined randomly. At this level WSCH-RDM combinations are tested. This level of integration was found very useful but this was not the ultimate level of integration. After that integration of weighted due date assignment with process plan selection is tested. At this level jobs are scheduled in random order. This level of integration is also found very useful and there were substantial improvements but scheduling in random order deteriorated performance back severely.

Finally fully integrated level is tested and process plan selection is integrated with weighted scheduling and weighted due date assignment and WSCH-WNOPPT combinations are tested and these combinations are found as the best combinations. This was the ultimate goal of this study and found as the best level as expected.

In this study six solutions are compared with each other. Poorest solution are the ordinary solutions which are randomly produced solutions. Among search techniques random search is found the worst search technique since it is an undirected search technique and does not get benefit of earlier solutions at every iterations. Although later iterations are very poor in random search, earlier iterations provide high marginal benefits and that’s why it is better to start with random search and scan solution space better and continue with other directed search techniques.

According to the results GA is found the best algorithm compared to the other search techniques but hybrid search techniques such as R-ES and R-GA found promising search techniques. At the hybrid search techniques it is better to start with random search but percentage of random search should not be very high since marginal benefit of random search diminishes sharply.

Table5. Comparison of twenty four combinations for four shop floors

	Shop Floor1			Shop Floor2			Shop Floor3			Shop Floor4			Shop Floor5			Shop Floor6			Shop Floor7			Shop Floor8		
Level of Integration	Best	Avarage	Worst	Best	Avarage	Worst	Best	Avarage	Worst	Best	Avarage	Worst	Best	Avarage	Worst	Best	Avarage	Worst	Best	Avarage	Worst	Best	Avarage	Worst
1-1-SIRO-RDM-OS	292	292	292	611	611	611	907	907	907	1337	1337	1337	1413	1413	1413	1724	1724	1724	2020	2020	2020	2490	2490	2490
1-1-SIRO-RDM-ES	269	272	275	552	564	568	824	836	841	1201	1208	1213	862	865	866	1065	1069	1073	1843	1862	1870	2309	2344	2351
1-1-SIRO-RDM-R-ES	248	252	255	523	533	539	827	835	839	1201	1224	1231	1031	1035	1038	1694	1715	1737	1869	1881	1889	2307	2325	2331
1-1-SIRO-RDM-GA	249	256	259	535	540	543	803	816	820	1201	1219	1224	1291	1301	1306	1579	1584	1587	1846	1857	1864	2273	2288	2295
1-1-SIRO-RDM-R-GA	265	269	272	545	549	553	814	818	822	1178	1183	1188	1306	1312	1316	1603	1611	1619	1857	1869	1878	2277	2293	2303
1-1-SIRO-RDM-RS	268	273	275	558	565	571	853	864	870	1254	1261	1266	1355	1372	1378	1610	1645	1657	1908	1925	1934	2346	2367	2378
1-2-WSCH-RDM-OS	266	266	266	560	560	560	802	802	802	1214	1214	1214	1346	1346	1346	1621	1621	1621	1886	1886	1886	2280	2280	2280
1-2-WSCH-RDM-ES	214	216	217	416	420	422	657	661	664	1009	1018	1024	1026	1031	1034	1263	1271	1275	1536	1544	1548	1808	1828	1833
1-2-WSCH-RDM-R-ES	206	208	209	430	438	440	652	657	660	965	971	976	1031	1035	1038	1330	1513	1652	1481	1488	1492	1835	1847	1851
1-2-WSCH-RDM-GA	218	219	219	441	446	450	676	678	679	989	998	1004	1093	1095	1097	1286	1287	1287	1523	1526	1529	1828	1831	1834
1-2-WSCH-RDM-R-GA	215	216	216	423	424	425	657	658	659	957	959	961	1037	1038	1039	1267	1269	1270	1464	1467	1469	1824	1825	1826
1-2-WSCH-RDM-RS	213	218	220	458	462	464	676	684	689	997	1014	1030	1086	1097	1108	1319	1338	1357	1531	1559	1583	1906	1943	1968
1-3-SIRO-WNOPPT-OS	287	287	287	609	609	609	838	838	838	1243	1243	1243	1315	1315	1315	1627	1627	1627	1938	1938	1938	2283	2283	2283
1-3-SIRO-WNOPPT-ES	245	253	257	513	524	531	815	821	824	1138	1179	1190	1256	1268	1277	1530	1540	1549	1795	1807	1818	2145	2163	2176
1-3-SIRO-WNOPPT-R-ES	239	251	256	527	530	533	815	821	826	1170	1185	1195	1254	1286	1292	1579	1639	1713	1759	1781	1791	2162	2176	2187
1-3-SIRO-WNOPPT-GA	231	238	241	487	495	501	749	757	760	1123	1136	1141	1229	1242	1249	1507	1512	1516	1753	1764	1773	2141	2152	2161
1-3-SIRO-WNOPPT-R-GA	240	242	244	491	497	499	759	764	765	1115	1128	1134	1229	1238	1242	1503	1522	1529	1719	1730	1742	2087	2116	2134
1-3-SIRO-WNOPPT-RS	252	259	264	511	522	528	807	815	821	1177	1187	1195	1274	1287	1292	1528	1553	1562	1779	1801	1815	2173	2210	2223
1-4-WSCH-WNOPPT-OS	208	208	208	488	488	488	654	654	654	962	962	962	993	993	993	1265	1265	1265	1463	1463	1463	1774	1774	1774
1-4-WSCH-WNOPPT-ES	178	181	182	360	364	367	570	571	572	846	854	859	888	893	897	1093	1104	1111	1308	1318	1321	1602	1611	1617
1-4-WSCH-WNOPPT-R-ES	178	179	181	357	361	364	567	571	573	852	857	862	888	895	898	1176	1288	1570	1291	1300	1304	1633	1650	1657
1-4-WSCH-WNOPPT-GA	175	176	177	402	405	406	599	605	609	845	851	853	862	865	866	1065	1069	1073	1282	1287	1290	1623	1629	1632
1-4-WSCH-WNOPPT-R-GA	176	177	179	398	399	400	585	587	588	847	854	857	873	877	880	1065	1074	1077	1286	1291	1293	1565	1571	1575
1-4-WSCH-WNOPPT-RS	189	192	193	414	420	423	624	632	636	892	901	910	916	930	942	1119	1134	1142	1301	1332	1353	1626	1666	1689

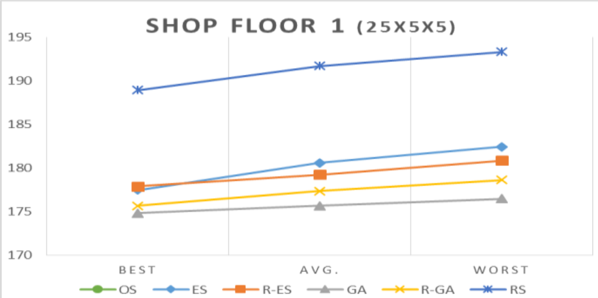

Figure 2. Shop Floor 1 (Highest level of integration)

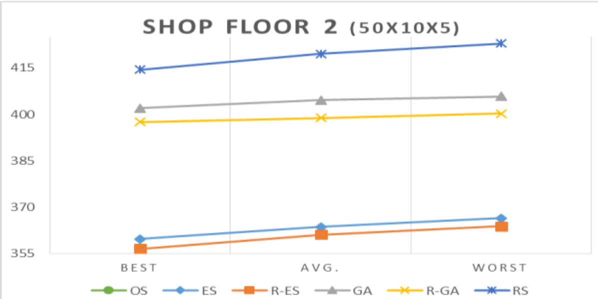

Figure 3. Shop Floor 2 (50x10x5)

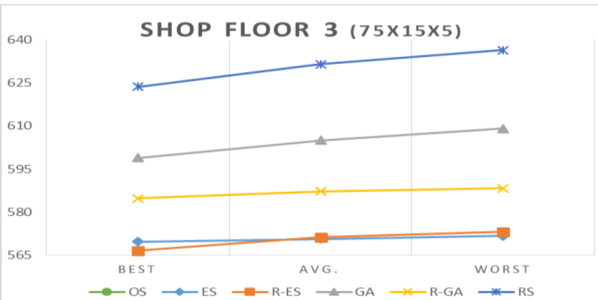

Figure 4. Shop Floor 3 (75x15x5)

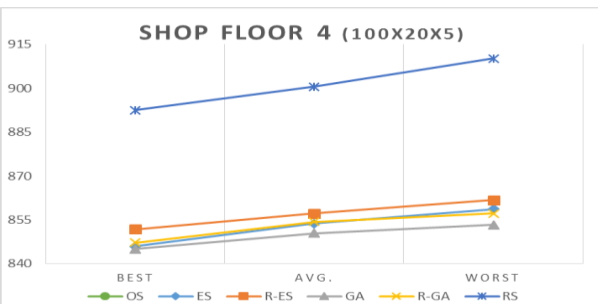

Figure 5. Shop Floor 4 (100x20x5)

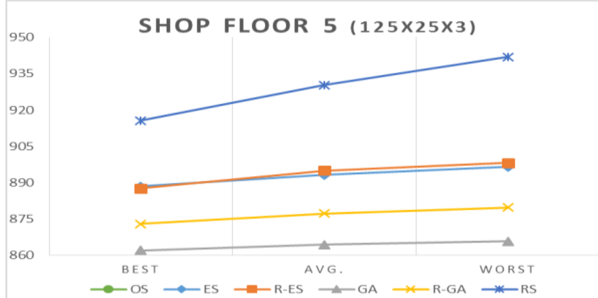

Figure 6. Shop Floor 5 (125x25x3)

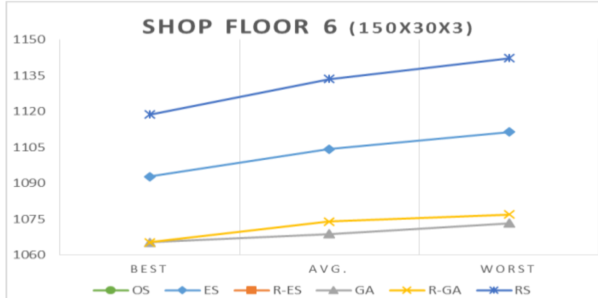

Figure 7. Shop Floor 6 (150x30x3)

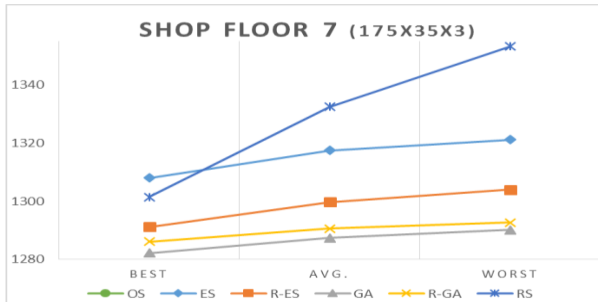

Figure 8. Shop Floor 7 (175x35x3)

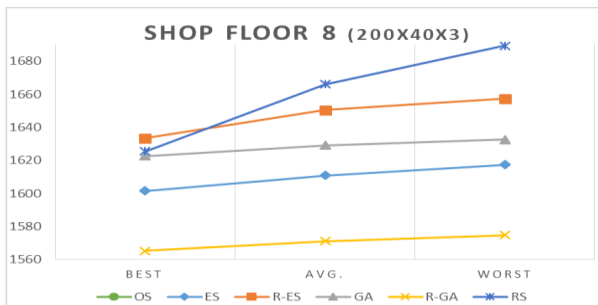

Figure 9. Shop Floor 8 (200x40x3)

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