Solving Process Planning, WATC Scheduling and Due-date Assignment Problem Concurrently Using Genetic and Hybrid Search Algorithms for Weighted Customers

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Abstract

Traditionally process planning, scheduling, and due-date assignment functions are applied sequentially and separately. Since these three functions affect each other and if we don't integrate, then they will become poor input for downstream and overall performance will be poor. In this competitive era, we must be competitive also. Integrating these functions will improve overall performance. In this study, we investigated the benefit of integration. We tested different integration level. First, we looked at unintegrated results and later step by step three functions are integrated and finally, we integrated these two functions with WATC (Weighted Apparent Tardiness Cost) Dispatching. In this study, we observed that as integration level increases the solution becomes better. Integrating due-date assignment or scheduling with process planning improves overall performance and if we integrate WATC dispatching with these two functions then we get the best performance. In addition to integration levels, we also compared the benefit of search techniques, especially genetic (directed) and hybrid (semi-directed) searches. At this study every customer has weight and they are scheduled by considering weights to improve performance value.

Keywords: Due-date assignment, Process planning, Job shop scheduling, Genetic Algorithm, Hybrid Search

1. INTRODUCTION

Traditionally process planning, scheduling, and due-date assignment functions are applied consecutively and individually. Hence the output of upper stream becomes input to downstream, we should not ignore effects of the upper stream and relations between them. If process planning applied individually then it does not consider about downstream and can select the repeatedly same desired machine. It would not produce alternative process plans in case of needs such as bottleneck situation and other unexpected occurrences like machine breakdown etc. Thus, preferred machines may have a bottleneck and other machines might have a shortage. In real life, individually prepared process plans may not be followed on the shop floor. Because of poor input to scheduling and due-date assignment, overall performance can be poor. If we want to improve overall performance in a competitive market, we need to integrate these functions. A study focusing on overall performance challenge on the level of integration will be promising. In this study, we tested different integration level. Initially, we tested an unintegrated solution, after that process planning is integrated with WATC dispatching, later we integrated due-date assignment with process planning and finally, we integrated WATC dispatching with these two functions and we observed that integration level increases the overall performance.

If process plans are prepared independently, they can be poor input to downstream. If alternative plans are not prepared and process planners select same machines every time they want and if they do not consider machine breakdowns and other unexpected occurrences, prepared plans to become unrealistic at shop floor level and 20% to 30% plans are not followed at shop floor level according to surveys. Repeatedly selected machines become a bottleneck and unselected machines become idle.

"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" [1]. i.e. completion of any task before the due date is also a resource allocation problem in the just-in-time environment. It creates inventories and consumes valuable shop floor areas.

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2. RELATED RESEARCHES

On a literature search, we might see numerous work on the integration of process planning and scheduling (IPPS). Two functions are tried to be integrated and later we will mention literature on this integration with more details. We may solely provide an exact solution of the integrated problem for only small problems. But when we increase the size we need some other ways to find a better solution. If we look at the literature, we can see heuristic solutions to find a better solution to the problem. Since job shop scheduling problem is NP-hard problem, the integrated problem is even more complex. That's why some researchers split the problem into loading and scheduling subproblems. Initially, they select one of the alternative process plans and decides to load and later they decide to schedule according to selected routes of the jobs. Researchers tried to integrate these two functions to improve overall performance according to some criteria such as; earliness, tardiness, average work-in-process, average machine utilization etc.

If we make a literature survey for late decades we can see extensive research on scheduling with due date assignment (SWDDA). SWDDA have received considerable attention in the last two decades due to the introduction of new operations management concepts and methods such as just-in-time production and supply chain management. In traditional scheduling system, due dates are considered as exogenously given. However, in many practical situations, due dates are endogenously decided that considers the production system's ability to meet the quoted due dates. Many studies consider due date assignment as part of the scheduling process and show that how firms' ability to control due dates can be a major factor for improving their performance [2]. Some researchers investigated single machine scheduling with the due-date assignment (SMSWDDA) and some other researchers studied multiple machine scheduling with due date assignment (MMSWDDA). Lately, there is numerous work on schedule with due window assignment (SWDWA). In this case, researchers tried to determine due to the window instead of a due date. In the later case, starting time and size of the window are tried to be determined. In these problems, some objectives are tried to be minimized. These objectives (costs) can be earliness, tardiness, number of tardy jobs, due date cost, due window assignment cost etc.

When we look at the literature on integration of process planning, scheduling, and due date assignment (IPPSDDA), we see few works on the integration of these three functions. Demir and Taskin [3] worked on a Ph.D. thesis on IPPSDDA. Demir et al. [4] presented benefit of integrating these three functions. They used genetic search, random search, and hybrid search to integrate these three functions and to find a good solution to the integrated problem. They compared these solutions with an ordinary solution and with each other. They tried to minimize weighted earliness and tardiness penalty. Ceven and Demir [5] integrated due date assignment with IPPS and tried to find benefits of integrating due date assignment with IPPS.

If we look at literature in a detailed way and part by part, we can list the following works. Initially, if we mention about IPPS we can see mainly following studies: Tan and Khoshnevis [6] presented a good literature survey on IPPS. As a beginning, it will be useful to see a survey on IPPS. We can also give Li et al [7] and Phanden et al [8] as surveys on IPPS problem.

In IPPS problems there are different flexibilities possible. These flexibilities are Operating Flexibility (OF), Process Flexibility (PF), Routing Flexibility (RF) and Operation Number Flexibility (ONF) Kim et al [9]. In this study we have RF and through genetic algorithm, we try to select better due date assignment method and WATC dispatching rule with better parameter and a better route for each job to get a better overall solution.

For the earlier works on IPPS we can list following researches; Nasr and Elsayed [10], Usher [11], Jiang and Hsiao [12], Morad and Zalzala [13].

Since mathematical techniques are only possible for small sized problems, other methods are utilized to find a better solution for the IPPS problem. Artificial intelligent techniques such as genetic algorithms, evolutionary algorithms, multi-agents and neural network are some widely used solution techniques. Morad and Zalzala [13] used genetic algorithms in IPPS problem. Moon et al. [14] formulated IPPS as a mathematical model and used genetic-algorithm-based heuristic approach to obtain good approximate solutions for the problem in the multi-plants supply chain. Kim et al. [15] presented an artificial intelligent search technique called symbiotic evolutionary algorithm to handle the IPPS problem. Lee and Kim [16] used the simulation-based genetic algorithm in IPPS problem. Leung et al. [17] presented an ant colony optimization in an agent-based system to integrate process planning and shop floor scheduling. Moon and Seo [18] formulated IPPS as a mathematical model and developed evolutionary algorithm to solve the model. Shao et al. [19] studied IPPS problem and used modified genetic algorithm-based approach for this purpose. Li et al. [20] presented a new hybrid algorithm based approach to facilitate the integration and optimization of process planning and scheduling.

Some other recent works on IPPS can be listed as Li et al. [21], Wang et al. [22], Seker et al. [23], Moon et al. [24], Guo et al. [25], Li et al. [26].

In this study, we have mentioned in several places about the benefit of flexible and alternative process plans. Now it is easier to prepare process plans by using computers and computer-aided process planning (CAPP) has been developed. Kumar and Rajotia [27] discussed the integration of scheduling with CAPP.

The second part of the problem is SWDDA. This part of the problem studied extensively in the literature. Due dates can be determined externally or internally. Sometimes due dates are determined by the customer and sometimes we negotiate due date with the customer and determine the due date as a part of the problem. If due dates are determined externally we try to improve scheduling performance to minimize the sum of some cost objectives. If we can determine due date internally integrated with scheduling, we can get improved overall solution. Due-date determination methods used commonly in literature. Recent years many works are done on SWDDA. A survey of these works is given in the following part of this section. To be more competitive firms should make use of every new idea and technological developments and wisely determined due dates improve overall solution.

According to the traditional approach, only tardiness is penalized but after JIT philosophy earliness is also punished. Earliness means every cost related to stock holding. Studies show that tardiness still the major component in due-date related costs. There might be fixed and variable terms in tardiness cost. These costs represent price reduction, loss of customer goodwill and worst losing customer and good reputation. In this research, we penalized weighted earliness, tardiness, and due-date costs.

If we look at the literature on SWDDA we can list mainly following researches. If we look at works in this area we can see that some works are conducted on single machine environments and some works are done on multiple machine environments. Machine environments can be flow shop, job shop, two machines, identical machines, different machines and n machines etc. In our research, we have n different machines and m jobs with 5 or 3 alternative process plans according to given shop size and 10 operations in each route. Each job is assigned a due date and performance of integrated process planning and due date assignment with a powerful dispatching rule WATC which has three different multipliers is tried to be improved. We assigned a due date for each job but many types of researches in the literature assign a common due date for the jobs. We can consider this cases as when finished or semi-assembled parts should be ready at the same time for final assembly. This time is the common due date for the semi-assembled or finished parts. Gordon et al. [28] made a good survey about scheduling with common due date assignment.

If we give some literature for single machine case: Cheng et al. [29], Lin et al. [30], Nearchou [31], Xia et al. [32], Gordon and Strusevich [33] studied single machine scheduling with due date assignment with some variances.

Following literature are some examples of multiple machine problems. Cheng and Kovalyov [34], and Lauff and Werner [35] studied multiple machine problems. In this investigation, we have multi-machines and multi-jobs each has its own due date.

Although there is numerous work on SWDDA for a couple of decades, lately we can see many works on SWDWA. In the previous case we assign a due-date and penalize earliness or tardiness but in the latter case, we assign a due-window instead of a point. In this case, location and size of the window are important and these values should be determined.

In addition to above one machine and multi-machine case literature following works are also on scheduling with due date assignment. Li et al. [36], Zhang and Wu [37], Yin et al. [38] tried to assign due dates with scheduling.

Lately, numerous works are done on SWDWA where due windows are assigned to jobs instead of due-dates. If jobs are completed within due-window, no penalty occurs and if jobs are completed out of due windows then earliness or tardiness occurs.

Cheng et al. [39], Yin et al. [40], Wang et al. [41], Ji et al. [42], and Yang et al. [43], studied scheduling with a due-window assignment with some variations.

In literature, there are variations of SWDDA, SWDWA problems. In some researches we can see the aging effect, deteriorating rate-modifying activity, learning and forgetting effect, controllable processing times, stochastic or fuzzy processing times, job dependent or job independent earliness and tardiness, batch delivery, single machine case, multi-machine case and problems with maintenance activity. Following literature are about variations of SWDDA and SWDWA problems. Yang et al. [43], Yin et al. [38], Cheng et al. [39], are some variations for SWDDA and SWDWA problems.

3. PROBLEM DEFINITION

We tried to integrate WATC dispatching rule with process planning and due-date assignment. There are alternative routes to improve overall performance and different due-date assignment methods are used to find better due dates. Instead of random scheduling, we integrated WATC dispatching rule with process planning and due-date assignment as a powerful rule to improve overall performance. We have three shop floors; small, medium and large shop floors. In case of small and medium shop floors we have five alternative routes and for the large shop floor, we have three alternative routes to select from. One of these alternative routes is selected for downstream. We used five different due-date assignment methods which are TWK (Total Work), SLK (Slack), PPW (Processing plus Wait), NOP (Number of operations) and RDM (Random due assignment). Here first four rules are used for internal due date assignments and fifth rule RDM due-date assignment rule is used for external due-dates. By comparing internal due-date assignments with external due-dates we observed the benefit of integration of due-date assignments with other two functions. With different multipliers and constants, we totally used nineteen different due-date assignments. Here we used mainly two dispatching rules which are WATC dispatching and SIRO (Service in Random Order) dispatching rules. WATC dispatching rule is selected as a powerful dispatching rule and compared with SIRO dispatching rule which sequence jobs randomly. By selecting WATC and SIRO dispatching rules we observed the benefit of integration of powerful dispatching rules with other two functions. In this study, we compared twelve different solutions that use a different level of integrations and different search techniques. These solutions are explained in section five.

We studied three shop floors as we mentioned these shops are small, medium and large shop floors. For instance, small shop floor has 50 jobs and 10 machines. Each job has five alternative routes and one of them should be selected. Processing times are randomly produced. Features of shop floors are given in Table 1 below.

Table 1. Shop Floors

Shop floor	Shop floor 1	Shop floor 2	Shop floor 3
# of machines	10	20	40
# of Jobs	50	100	200
# of Routes	5	5	3
Processing Times	MG1 = 10+(Z) *5, MG2 = 12+(Z) *6, MG3 = 14+(Z) *7		
# of op. per job	10	10	10

Table 2. Probability of Selecting Machine Groups

SF	R\MG	MG1	MG2	MG3
SF1, SF2	R1	0,8	0,1	0,1
	R2	0,6	0,25	0,15
	R3	0,33	0,33	0,34
	R4	0,2	0,3	0,5
	R5	0,1	0,2	0,7
SF3	R1	0,7	0,2	0,1
	R2	0,33	0,33	0,34
	R3	0,2	0,2	0,6

SF= Shop Floors, R=Route, MG=Machine Group,

Table 2 shows the probability of selecting machine groups. Every job has 10 operations and operation time changes according to the machine groups. Machine Group-1 (MG1) represents relatively new (modern) machines whereas MG2 represents average machines and MG3 represents relatively old machines.

We penalized earliness and tardiness with a fixed and variable cost. Earliness and tardiness and due-dates are penalized linearly. Each job is also punished according to its weight. We assumed one shift per day and 8 hours * 60 minutes = 480 minutes are considered as one day. Due dates are punished with the weight of given job times constant coefficient 8 times due-date. Earliness is punished with a fixed cost 5 plus 4 times earliness and multiplied with the weight of the given job. Tardiness is punished with a fixed cost 10 plus 12 times tardiness in terms of the day are occurred and multiplied with the weight of the given job. Penalty functions of due-date, earliness and tardiness are given below:

$$\mathrm{PD}_j = W_j \times 8 \times \left(\mathrm{D}/480\right) \quad (1)$$

$$\mathrm{PE}_j = W_j \times \left(5 + 4 \times \left(\mathrm{E}/(480)\right)\right) \quad (2)$$

$$\mathrm{PT}_j = W_j \left(10 + 12 \times \left(\mathrm{T}/480\right)\right) \quad (3)$$

$$\mathrm{P}_j = \mathrm{PD}_j + \mathrm{PE}_j + \mathrm{PT}_j \quad (4)$$

$$\mathrm{TP} = \sum_j P_j \quad (5)$$

Where,
D_j = Due-date of job j
E_j = Earliness of job j
T_j = Tardiness of job j
PD_j = Penalty for Due-Date for job j
PE_j = Penalty for Earliness for job j
PT_j = Penalty for Tardiness for job j
W_j = Weight of Job j
P_j = Total penalty occurred for a job
TP = Total penalty occurred for all the jobs totally

4. SOLUTION TECHNIQUES

In this research, we compared genetic, random, and hybrid searches. For small shop floor we made 200 iterations, for medium shop floor we applied 100 iterations and for the large shop floor, we applied 50 iterations. Best results of these iterations are recorded as the solution of genetic, hybrid and random searches.

Random Search: This is an undirected search and scans solution space randomly. As iteration goes on marginal benefits of this search gets smaller. We have less chance to find a better solution than up to date best solution. We do not get the benefit of earlier iterations always we produce brand new solutions randomly and compare these solutions with previous solutions and record best solutions ever found as updated new population.

Genetic search: This search is directed search. It uses the previous population and uses crossover and mutation operator. Here better chromosomes have a higher probability to be selected for crossover and mutation operators to produce new offspring. Since this search uses best solutions found and can get the benefit of earlier iterations, it is called directed search and scans solution space around best solutions found.

At every iteration (generation) six new offspring (chromosomes) are produced using crossover operator and four new off springs are produced using mutation operator. From old population, crossover and mutation populations, best ten chromosomes are selected as the new population. We repeat iterations until predetermined value.
At the following Figure 1, a sample chromosome (solution) is given. We have (n+2) genes in each chromosome and the first gene is for due-date assignment, the second gene is for dispatching rule and rests are for routes of each n jobs.

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

Where
DD: Due date assignment gene
DR: Dispatching rule gene

Figure 1. Sample chromosome

Hybrid Search: Since random searches are only useful at the very beginning of the hybrid algorithms, we applied %5 random iterations and later we applied %95 genetic iterations. According to the results, the hybrid search is found promising search technique.

Due dates were assigned using mainly five different types of rules. Considering different constants and multipliers the first gene took one of nineteen values. These rules are first TWK rule where total processing times are multiplied by 1 or 2 or 3 to find the due-date of given job. SLK stands for slack and due-date are found by adding some constant to the total processing time of given job. Slack constants are used as $q1=P_{av}/2$, $q_2=P_{av}$, $q_3=3*P_{av}/2$. P_{av} (mean processing time of all job waiting), PPW technique is a hybrid of TWK and SLK techniques, NOP technique assigns due-date as multiplying total processing time with a predetermined number. Finally, RDM due date assignment rule assigns due-dates randomly. According to RDM technique, these dates are found by using normal distribution ([N~ (3*P_{av}, $(P_{av}/2)^2$)]) with mean 3*P_{av} and variance $(P_{av}/2)^2$. Due date assignment rules are given in Table 3.

Table 3. Due-Date Assignment Rules

Method	Multiplier k	Constant q_x	Rule no:
TWK	k = 1,2,3		1,2,3
SLK		$q_x = q_1, q_2, q_3$	4,5,6
PPW	k =1,2,3	$q_x = q_1, q_2, q_3$	7,8,9,10,11,12, 13,14,15
NOP	k = 1,2,3		16,17,18
RDM			19

According to the Table 4, Four dispatching rules are given. We have mainly two dispatching rules and with different multipliers, we have four rules and the second gene in a chromosome takes one of these four values.

Table 4. Dispatching Rules

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

5. SOLUTIONS COMPARED

WATC-DUE (Random, Genetic, Hybrid): In this solution, three functions, process planning, scheduling and due-date assignment are integrated. We tested random, genetic, and hybrid search solutions in this step. Genetic and hybrid searches are found superior to the random search. Since this is the highest level of integration best results are obtained at this level.

SIRO-DUE (Random, Genetic, Hybrid): In this case, we integrated process planning with the due-date assignment, but sequencing and scheduling performed randomly.

WATC-RDM (Random, Genetic, Hybrid): Here WATC scheduling is integrated with process plan selection but due dates are determined randomly.

SIRO-RDM (Random, Genetic, Hybrid): In this case, process plan selection is performed unintegrated with scheduling and due-date assignment. Jobs are sequenced randomly, and due dates are determined externally.

We compared twelve cases to determine the benefit of integration levels and directed and undirected searches. As it can be seen at the experimentation part as integration level increases solution becomes better. Totally integrated level found as the best level and totally unintegrated level found as the poorest level. We also observed that directed search outperforms undirected search. So, we propose to integrate three functions as much as possible and to use genetic or hybrid searches to find a satisfactory solution.

6. EXPERIMENTS AND RESULTS

We integrated three functions, process plan selection, scheduling and due-date assignment. We applied genetic, hybrid and random searches to find a good solution. We coded integrated problem, process plan selection, scheduling, due-date assignment, random search, and genetic search and hybrid searches by using C++ language and tested the problem on a notebook with 2 GHz processor. For three shop floors, we applied given several genetic, random or hybrid iterations.

We integrated three functions step by step and observed solutions. Solutions became better as integration level increased. First, we tested unintegrated cases, after that, we integrated WATC dispatching with process plan selection, later we integrated due-date assignment with process planning and finally, we integrated three functions.

We tested three shop floors for twelve cases and observed the following results given in table 5 and Figure 2, 3, and 4. If we look at the results directed, and hybrid searches gave best results compared to the random search. Most of the time genetic search is found best, sometimes hybrid search is outperformed genetic search and random search is found the poorest.

Performance measure here in Table 5 is the total penalty occurred for all the jobs in terms of weighted earliness, tardiness, and due date related costs.

Table 5. Comparison of Twelve Types of Solutions for Small, Medium and Large Shop Floors

Shop Floor 1												
	SIRO-RDM			WATC-RDM			SIRO-DUE			WATC-DUE		
	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst
RS	597,2	607,1	615,1	540,3	544,9	547,8	556,6	564,5	569,4	518,7	529,8	539,0
GA	529,3	536,2	539,1	464,7	474,7	478,9	480,3	489,2	493,5	432,3	438,2	441,6
HS	539,1	545,7	549,4	458,4	464,1	468,0	525,7	531,7	534,8	460,4	464,4	467,1
Shop Floor 2												
	SIRO-RDM			WATC-RDM			SIRO-DUE			WATC-DUE		
	Best	Avg	Worst	Best	Avg	Worst	Best	Avg	Worst	Best	Avg	Worst
RS	1291,0	1295,6	1298,9	1154,7	1174,5	1185,8	1156,0	1188,6	1199,7	1099,5	1121,1	1132,6
GA	1195,7	1209,2	1216,1	1107,3	1111,8	1114,4	1087,4	1099,7	1105,2	987,2	992,9	995,8
HS	1201,1	1204,5	1208,1	1072,9	1083,0	1086,9	1104,0	1109,8	1112,7	996,3	1008,0	1013,7
Shop Floor 3												
	SIRO-RDM			WATC-RDM			SIRO-DUE			WATC-DUE		
	Best	Avg	Worst	Best	Avg	Worst	Best	Avg	Worst	Best	Avg	Worst
RS	2681,0	2706,1	2720,6	2423,7	2439,1	2446,8	2450,3	2481,0	2500,3	2317,9	2369,1	2396,7
GA	2601,3	2608,6	2616,9	2340,6	2343,3	2345,3	2300,0	2317,6	2322,5	2135,0	2141,6	2147,1
HS	2575,9	2593,3	2601,0	2319,1	2331,1	2337,2	2352,3	2374,4	2385,6	2233,9	2253,3	2261,5

Similar results are obtained for medium and larger shop floors and full integration with genetic search mostly gave the best results. Sometimes hybrid search gave best results in intermediate integrated levels and best result for the largest shop floor for the fully integrated level.

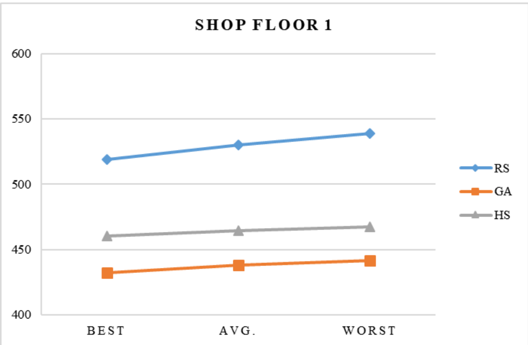

Figure 2. Small shop floor results

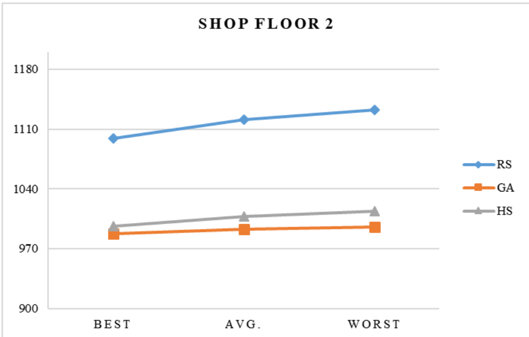

Figure 3. Medium shop floor results

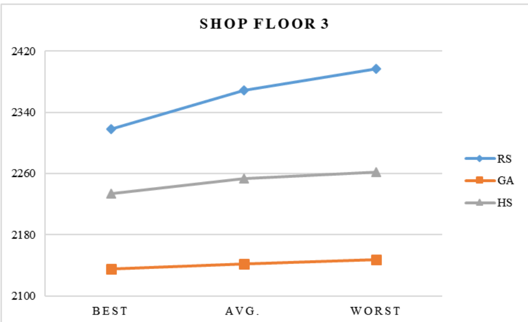

Figure 3. Large shop floor results

7. CONCLUSIONS

In this study, we studied the integration of three functions; process planning, scheduling and due-date assignment gradually. When we reviewed the literature, there are some studies on integrated process planning and scheduling and on scheduling with the due-date assignment. But there are not so many studies on integrating these three functions. In this research, we focused on these integrations. We tested unintegrated solutions and then we integrated three functions one by one and finally we integrated these two functions with scheduling using WATC dispatching.

As we mentioned earlier we tested different integrations on each level and we integrated these three functions gradually. Initially, we tested unintegrated combinations. When we observed the results, we identified that unintegrated solution is the poorest solution. After that, we integrated WATC dispatching with process plan selection, but due dates are determined randomly. Later we integrated due-date assignment with process plan selection and still, we used random scheduling which represents unintegrated scheduling. Finally, we integrated three functions. The fully integrated version has been found as the best level of integration.

According to literature survey, we observe that integrating process planning and scheduling increases overall performance and has many benefits according to unintegrated solutions. There are numerous studies has been done in this area. Also, there are numerous studies on scheduling with the due-date assignment. And concurrent due-date assignment and scheduling also increases overall performance and provide substantial benefits. When we consider integrating these three function we have not found so many studies in this area. This research focused on proving the benefit of integration and results showed that integrating these three functions is very lucrative. In this research, we also observed that searching for a better solution is very useful and we found that the genetic and hybrid searches outperform the random search. As a summary, we found that as integration level increases solution becomes better and search for a better solution is very useful and directed search always outperforms undirected search. In the smallest and medium shop floors, generally genetic search gave the best result for the inttermadiate and fully integrated levels. Hybrid search is found a promising search technique and gave better results for some intermediate levels and at the largest shop floor, generally hybrid search gave better results compared to the genetic search. If we do not integrate these functions, then each function tries to get local optima and does not focus on overall optimum. Since earlier functions are input to later functions unintegrated solution produce poor inputs to downstream functions.

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