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Solving Process Planning, ATC Scheduling and Due-date Assignment Problems Concurrently Using Genetic Algorithm 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 effect each other and if we don't integrate then they will become poor input for downstream and global performance will be poor. In these competitive era we have to be competitive also. Integrating these functions will improve global performance. In this study we investigated the benefit of integration. We tested different integration level. First we looked at unintegrated results and later we integrated due-date assignment with process planning and finally we integrated these two functions with ATC (Apparent Tardiness Cost) Dispatching. In this study we observed that as integration level increases the solution becomes better. Integrating due-date assignment with process planning improves global performance and if we integrate ATC dispatching with these two functions then we get the best performance. In addition to integration level we also compared benefit of search techniques, especially genetic (directed) search. We compared ordinary solutions (initial populations) with results of random search and genetic search (after some certain number of iterations). We tested three shop floors which are small, medium and large shop floor. We observed that search is always better than ordinary solutions and genetic search outperformed random (undirected) search. At this study every customer has weight and they are scheduled by considering weights to improve performance value.

Key words: Due-date assignment, Process planning, Job shop scheduling, Genetic Algorithm

1. Introduction

Traditionally process planning, scheduling and due-date assignment functions are applied sequentially and separately. Since output of upper stream becomes input to downstream, we should not ignore effects of upper stream and relations between them. If process planning applied separately then it doesn't care about downstream and can select repeatedly same desired machine. It may not prepare alternative process plans in case of needs such as bottleneck situation and other unexpected occurrences like machine breakdown and others. Consequently desired machines can be bottleneck and some other machines can be starving. In real life separately prepared process plans may not be followed at the shop floor. As a result of poor input to scheduling and due-date assignment global performance can be poor. If we want to improve global performance and become a better competitor in competitive market we need to integrate these functions. A research that investigate global performance according to some level of integration will be useful. In this study we tested different integration level. Firstly we looked at unintegrated solution, later we integrated due-date assignment with process planning and finally we integrated ATC dispatching with these two functions and we observed that integration level increases the global performance. If we look at each function;

Process planning has been defined by Society of Manufacturing Engineers as the systematic

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determination of the methods by which a product is to be manufactured economically and competitively. There were tremendous development in computer, hardware, software and algorithm and this made it possible to make process plans using computers. CAPP (Computer aided process planning) can be used for improved, better, reliable and easy process plans. After CAPP it is easy to produce alternative process plans. Alternative process plans provides us flexibility in case of need, becomes a better input to scheduling and due-date assignment. In case of congestion and high demand we can improve global performance (better scheduling and due-date assignment) and response to the case and can get improved solution.

Pinedo and Chao (1999) defined scheduling as a decision-making process that plays an important role in most manufacturing and service industries. According to Zhang and Mallur (1994) production scheduling is a resource allocator, which considers timing information while allocating resources to the tasks. Although process plans work one part at a time, scheduling considers all parts to be scheduled and try to assign resources to operations as it is specified by process plans.

If process plans are prepared independently, they can be poor input to downstream. If alternative plans are not prepared and process planners selects same machines every time they want and if they do not care machine breakdowns and other unexpected occurrences prepared plans become unrealistic at shop floor level and 20% to 30% plans are not followed at shop floor level. Repeatedly selected machines becomes 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"Gordon et al. (2002).

2. Related Researches

If we look at the literature we can see numerous work on integration of process planning and scheduling (IPPS). Two functions are tried to be integrated and later we will mention literature on this integration more. We may only find exact solution of the integrated problem for only small problems. But when we increase the size we need some other ways to find a good solution. If we look at the literature we can see heuristic solutions to find a good solution to the problem. Since job shop scheduling problem is NP-hard problem, integrated problem is even more complex. That's why some researchers divided problem into loading and scheduling sub problems. Initially they select one of alternative process plans and decides loading and later they decide scheduling according to selected routes of the jobs. Researchers tried to integrate these two functions to improve global performance according to some criteria such as; earliness, tardiness, mean work-in-process, mean 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 models due dates are considered as exogenously given. However, in many practical situations due dates are endogenously determined that takes into account 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 Yin et al (2013d). Some researchers investigated single machine scheduling with due-date assignment (SMSWDDA) and some other researchers studied multiple machine scheduling with due date assignment (MMSWDDA). Lately, there are numerous work on scheduling with due window assignment (SWDWA). In this case researchers tried to determine due window instead of a due date. In later case, starting time and size of 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 job, 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 function. Demir and Taskin (2005) worked on a Ph.D. thesis on IPPSDDA. Demir et al (2004) 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 (2007) 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 Khosnevis (2000) presented a good literature survey on IPPS. As a beginning, it will be useful to see survey on IPPS. We can also give Li et al (2010a) and Phanden et al (2011) 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 (2003). In this study we have RF and through genetic algorithm we try to select better due date assignment method and ATC dispatching rule with better parameter and better route for each job to get better global solution.

For the earlier works on IPPS we can list following researches; Nasr and Elsayed (1990), Jiang and Chen (1993), Usher (2003), Jiang and Hsiao (1994), Huang et al. (1995), Morad and Zalzala (1999) Since mathematical techniques are only possible for small sized problems, other methods are utilized to find 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 (1999) used genetic algorithms in IPPS problem. Moon et al (2002) formulated IPPS as mathematical model and used genetic-algorithm based heuristic approach to obtain good approximate solutions for the problem in multi-plants supply chain. Kim et al (2003) presented an artificial intelligent search technique called symbiotic evolutionary algorithm to handle the IPPS problem. Lee and Kim (2001) used simulation based genetic algorithm in IPPS problem. Leung et al (2010) presented an ant colony optimization in an agent-based system to integrate process planning and shop floor scheduling. Moon and Seo (2005) formulated IPPS as a mathematical model and developed evolutionary algorithm to solve the model. Shao et al (2009) studied IPPS problem and used modified genetic algorithm-based approach for this purpose. Li et al (2010b) 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 (2010c), Li et al (2010d), Li et al (2012b), Wang et al (2014), Seker et al (2013), Moon et al (2008), Guo et al (2009), Li et al (2012a).

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 (2003) discussed the integration of scheduling with CAPP.

Second part of the problem is SWDDA. This part of the problem studied extensively at the literature. Due dates can be determined externally or internally. Sometimes due dates are determined by customer and sometimes we negotiate due date with customer and determine due date as a part of the problem. If due dates are determined externally we try to improve scheduling performance to minimize 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 are given at the following part of this section. To be more competitive firms should make use of every new ideas and technological developments and wisely determined due dates improve overall solution.

According to traditional approach only tardiness is penalized but after JIT philosophy earliness is also punished. Earliness means every cost related with 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 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. Multiple 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 operation 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 ATC which has three different multipliers is tried to be improved. We assigned a due date for each job but many researches in the literature assigns 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 common due date for the semi assembled or finished parts. Gordon et al (2002) made a good survey about scheduling with common due date assignment.

If we give some literature for single machine case: Cheng et al. (2002), Cheng et al (2005), Lin et al (2007), Ying (2008), Nearchou (2008), Xia et al (2008), Gordon and Strusevich (2009), and Li et al. (2011) studied single machine scheduling with due date assignment with some variances.

Following literature are some examples to multiple machine problems. Cheng and Kovalyev (1999), Mosheiov (2001), and Lauff and Werner (2004) studied multiple machine problems. In this investigation we have multi-machines and multi-jobs each has its own due date.

Although there are numerous work on SWDDA for couple of decades, lately we can see many works on SWDWA. At the previous case we assign a due-date and penalize earliness or tardiness but at 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 literatures following works are also on scheduling with due date assignment. Shabaty (2010) , Li et al (2011), Li et al (2011a) , Li et al (2011b) , Zhang and Wu (2012) , Yin et al (2012a) , Yin et al (2012b) and Yin et al (2013a) tried to assign due dates with scheduling.

Lately numerous works are done on SWDWA where due windows are assigned for 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.

Mosheiov and Sarig (2010), Mor and Mosheiov (2012), Cheng et al (2012), Yin et al (2013c), Yin et al (2013b), Wang et al (2013), Ji et al (2013), Ji et al (2014), and Yang et al (2014) studied scheduling with due-window assignment with some variations.

In literature there are variations of SWDDA, SWDWA problems. In some researches we can see aging effect, deteriorating rate-modifying activity, learning and forgetting affect, 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 (2014), Yin et al (2013a), Yin et al(2013b), Yin et al (2012b), Zhao and Tang (2012), Cheng et al (2012), Li et al (2010) are some variations for SWDDA and SWDWA problems.

3. Problem Definition

We tried to integrate ATC dispatching rule with process planning and due-date assignment. There are alternative routes to improve global performance and different due-date assignment methods are used to find better due dates. Instead of random scheduling we integrated ATC 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 large shop floor we have three alternative routes to select from. One of these alternative routes is selected for downstream. We used mainly 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 is 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 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 ATC (Apparent Tardiness Cost) dispatching and SIRO (Service in Random Order) dispatching rules. ATC dispatching rule is selected as a powerful dispatching rule and compared with SIRO dispatching rule which sequence jobs randomly. By selecting ATC and SIRO dispatching rules we observed benefit of integration of powerful dispatching rules with other two functions. In this study we compared seven different solutions that uses different level of integrations and different search techniques or ordinary solutions. These solutions are explained at section five.

We studied three shop floors as we mentioned these shops are small, medium and large shop floors. Small shop floor has 50 jobs and 20 machines. Each job has five alternative routes and one of them should be selected. Every job has 10 operations and operation time changes in between 10 and 19 minutes (Processing times = $\lfloor(10+|z|*3)\rfloor$ = nearest small integer. $|z|$ is absolute value of standard normal numbers). Processing times are randomly produced.

Mid-sized shop floor is the second shop floor and it has 100 jobs and thirty machines. We have five different routes for each job and every job has 10 operations and operation times change in between 10 and 19 according to the same formula (Processing times = $\lfloor(10+|z|*3)\rfloor$ = nearest small integer. $|z|$ is absolute value of standard normal numbers) with other shop floors.

Largest shop floor is the third shop floor with 200 jobs and 40 machines. Because of required computational time and reduction of marginal benefit of new extra route we preferred three alternative routes for each job. Each of the jobs has 10 operations and operation times changes according to following formula (Processing times = $\lfloor(10+|z|*3)\rfloor$ = nearest small integer in between 10 and 19. $|z|$ is absolute value of standard normal numbers). Features of shop floors are given at Table 1 below.

Table 1. Shop Floors

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

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 of the job in terms of day. Earliness is punished with a fixed cost 10 plus 8 times earliness in terms of day are multiplied with the weight of the given job. Tardiness is punished with a fixed cost 10 plus 12 times tardiness in terms of day are multiplied with the weight of the given job. Penalty functions of due-date, earliness and tardiness are given below:

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

$$\mathrm{PE} = W_j \times (10 + 8 \times (\mathrm{E}/(480))) \quad (2)$$

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

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

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

Where,
D = Due-date
E = Earliness
T = Tardiness
PD = Penalty for Due-Date
PE = Penalty for Earliness
PT = Penalty for Tardiness
W_j = Weight of Job j
P_j = Total penalty occurred for a job
TP = Total penalty occurred for all of the jobs totally

4. Solution Techniques

In this research we compared genetic search, random search and ordinary solutions. We used average of initial populations as ordinary solutions but for genetic search and for random search we produced new populations as many as predetermined values. For small shop floor we made 200 iterations, for medium shop floor we applied 100 iterations and for large shop floor we applied 50 iterations. Best results of these iterations are recorded as the solution of genetic search or random search.

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

At every iteration (generation) eight new offsprings (chromosomes) are produced using crossover operator and five 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 first gene is for due-date assignment, second gene is for dispatching rule and rests are for routes of each n jobs.

Ordinary solution: We used three initially randomly produced population. One is main population with ten chromosome, second is the population equally sized with crossover population and third is equally sized with mutation population. From these three randomly produced populations we chose best ten chromosome as the initial population and used this population for the ordinary solutions.

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

Where
DD : Due date assignment gene
DR : Dispatching rule gene
R nj : i'th route of job n

Figure 1. Sample chromosome

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 TWK (Total work) here 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 q_1=Pav/2, q_2=Pav, q_3=3*Pav/2. PPW (processing plus wait) techniques is a hybrid of TWK and SLK techniques, NOP (Number of operations) techniques assign due-date as multiplying total processing time with a predetermined number. Finally, RDM (Random) due date assignment rules assign due randomly. In this study these dates are found by using normal distribution ($[N\sim(3*Pav,(Pav/2)^2)]$) with mean 3*Pav and variance $(Pav/2)^2$. Due date assignment rules are given at Table 3.

Table 2. 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

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

Table 3. Dispatching Rules

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

5. Solutions Compared

ATC-DUE (Ordinary,Random,Genetic): In this solution three functions, process planning, scheduling and due-date assignment are integrated. We tested ordinary solutions, Random Search solutions and Genetic Search solutions at this step. We applied genetic search until a predetermined value. For small shop floor we applied 200 genetic iterations, for medium shop floor we applied 100 and for large shop floor we applied 50 iterations. Since we get benefit of previous iterations this is directed search and gives better solutions than random search. Results can be found at the experimentation part.
SIRO-DUE(Ordinary,Genetic): In this case we integrated process planning with due-date assignment but sequencing and scheduling performed randomly. We tested ordinary solutions and genetic search solutions.
SIRO-RDM(Ordinary,Genetic): 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. Ordinary solutions and genetic search solutions are tested.
We compared seven cases to determine benefit of integration level and directed and undirected search. As it can be seen at the experimentation part as integration level increases solution becomes better. Totally unintegrated solution is the poorest and later we integrated due-date assignment with process plan selection and we observed that solution became better and later we integrated ATC dispatching with the other two functions and we observed the best solutions. We also observed that search is better than ordinary solution and directed search outperforms undirected search. So we propose to integrate three functions as much as possible and to use genetic search to find a good solution.

6. Experiments and Results

We integrated three functions, process plan selection, scheduling and due-date assignment. We applied genetic and random search to find a good solution. We coded integrated problem, process plan selection, scheduling, due-date assignment, random search and genetic search using C++ language and tested the problem on a notebook with 2 GHz processor. For three shop floors we applied given number of genetic or random iterations. For small shop floor we applied 200 random or genetic iterations and when we used SIRO dispatching it took approximately 90 seconds and when we used ATC dispatching it took approximately 160 seconds to finish 200 iterations. For medium sized shop floor we applied 100 random or genetic iterations. When we used SIRO as dispatching it took approximately 250 seconds and when we used ATC dispatching it took 450 seconds. For large shop floor we applied 50 iterations and when we used SIRO rule it took 520 seconds and when we used ATC rule it took approximately 900 seconds and results can be seen form the tables and figures.
We integrated three functions step by step and observed solutions. Solutions became better as integration level increased. First we tested unintegrated cases, Later we integrated due-date assignment with process planning and finally we integrated three functions and tested ATC-DUE (Genetic), ATC-DUE (Random), ATC-DUE (ordinary) cases. We looked at ordinary random solution and compared this solution with the solutions of random search and genetic search. At section five these solutions (cases) are explained in detail.
We tested three shop floors for seven cases and observed the following results given at the tables and figures. First shop floor we tested was small shop floor with 50 jobs with 10 operations and five different alternative routes and at this shop floor we have 20 machines and operation times

change in between 10 and 19 according to following formula . Three of the solutions are ordinary solutions and use the results of initial randomly produced population's results. One of the cases use random search and we apply 200 random iterations. Three of the cases use genetic search and we apply 200 genetic iterations. Results for the small shop floor is given below at Figure 2 and Table 5. Since we use initial randomly produced population for ordinary solutions, negligible amount of time required for these cases. For random search and genetic search if we use SIRO rule then approximately 90 seconds required to complete 200 iterations. If we use ATC rule then we need 160 seconds to finish 200 iterations and CPU times are given at Table 5. If we look at the results from Table 5 and Figure 2 we can see that fully integrated case is the best case and if we integrate process plan selection and due-date assignment with ATC dispatching then we get the best results. We can also see that if we integrate due-date assignment with process plan selection then we get better solution then unintegrated cases. Unintegrated solutions are the poorest cases. If look at the results we can observe that if we search better solutıons then we get better results compared to ordinary solutions. It can be seen also that directed search gives better result compared to undirected search.

Table 4. Comparison of Seven Types of Solutions For Small, Medium and Large Shop Floors

	Small				Medium				Large			
	Best	Avg.	Worst	CPU	Best	Avg.	Worst	CPU	Best	Avg.	Worst	CPU
ATC-DUE (O)	1112	854,77	791,12		2101,59	1782,6	1689,31		4513,62	4131,44	4015,38	
SIRO-DUE(O)	1123,34	861,82	798,6		2119,75	1820,74	1711,35		4655,84	4321,3	4126,12	
SIRO-RDM(O)	932,72	925,84	916,16		1853,21	1822,41	1794,78		4218,29	4181,03	4144,91	
ATC-DUE (R)	778,34	776,02	772,73	154sec	1684,46	1680,48	1666,68	442sec	3946,26	3937,96	3932,03	860sec
ATC-DUE (G)	757,33	756,16	754,99	156sec	1644,54	1643,06	1639,9	450sec	3831,81	3829,47	3824,05	900sec
SIRO-DUE(G)	773,71	771,76	768,44	85sec	1686,91	1684,44	1676,25	254sec	4050,19	4044,27	4023,4	526sec
SIRO-RDM(G)	900,9	899,47	895,29	87sec	1781,85	1778,75	1769,31	242sec	4056,24	4047,39	4036,79	500sec

Figure 2. Small shop floor results

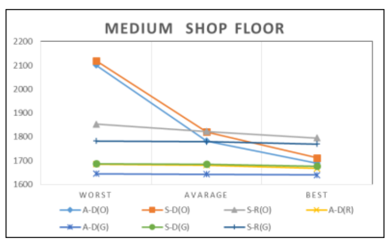

Figure 3. Medium shop floor results

Figure 4. Large shop floor results

Similar results are obtained for medium and larger shop floors and full integration with genetic search gave the best result.

Conclusions

In this study we studied integration of three functions, process planning scheduling and due-date assignment step by step. When we looked at the literature there are works on integrated process planning and scheduling and on scheduling with due-date assignment. But there are not much works on integrating these three functions. In this research we tried this integration. We tested unintegrated solutions and then we integrated process plan selection with due-date assignment and finally we integrated these two functions with scheduling using ATC dispatching.

As we mentioned earlier we tested different integration level and we integrated these three functions step by step. At first we tested unintegrated combinations. When we observed the results we saw that unintegrated solution is poorest solution. As a next step we integrated due-date assignment with process plan selection and still we used random scheduling which represent

unintegrated scheduling. Finally we integrated three functions and fully integrated version is found as the best level of integration.
If we look at the literature we can see that integrating process planning and scheduling increases global performance and has many benefits compared to unintegrated solutions. There are numerous work done on this area. Again there are numerous work on scheduling with due-date assignment. And concurrent due-date assignment and scheduling also increases global performance and provide substantial benefits. When we consider integrating these three function we don't see much work on this area. This research aimed to prove benefit of integration and results proved that integrating these three function is very beneficial. In this research we also observed that searching for better solution is very useful and we found that the genetic search outperforms the random search. As a summary we found that as integration level increases solution becomes better and search for better solution is very useful and directed search always outperforms undirected search. If we do not integrate these functions each function tries to get local optima and doesn't care about global optimum. Since earlier functions are input to later functions unintegrated solution produce poor inputs to downstream functions.

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