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Concurrent Solution of WATC Scheduling with WPPW Due Date Assignment for Environmentally Weighted Customers, Jobs and Services Using SA and its Hybrid

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ABSTRACT

After industrial revolution environmental problems increased drastically. Air, water and soil pollution became a serious threat for the mankind. In order to overcome this threat everyone should take responsibility and try to preserve environment as much as possible. Environmentally conscious actions, people, law and foundations should be supported. When it came to determining due dates and scheduling, one of the important criteria should be the supporting the environment. In this study environmentally conscious customers, jobs, and services are rewarded, on the other hand unconscious customers, jobs, and services are penalized, while determining due dates and schedules. Simulated annealing and its hybrid with random search are applied to get environmentally better due dates and schedules.

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1. Introduction

Energy demands of developing countries has been increased rapidly with the globalization and technology developments [1]. Almost half of the world's total energy is consumed by manufacturing industries [2]. Relatively rapid increase of energy consumption rates triggers global warming and cause serious environmental problems. Due to environmental issues, organizations and manufacturing systems are encouraged for research and development (R&D) over renewable energy sources such as sunlight, wind, flowing water, the earth's internal heat and green [3]. Sustainable economic development may be real if manufacturing become environmental friendly [4], [5].

For the same purpose, organizations have also researched intensively in the field of job scheduling because the interest on environmental friendly production is increased. Job scheduling deals with the assignment of the jobs in which to be done in the process from the raw material to the finished product to the machines. An evaluation of job shop dispatching rules was conducted in paper [6]. Thus, it is ensured that the customer which has more importance for the manufacturer has a priority. In a typical scheduling model, weight of customers are determined with the quantities in the order list. In this study, a distinction was made between the customers regarding their consciousness in environmental friendly production. It is aimed to encourage the manufacturers who produces environmental friendly products by scheduling them firstly. A substantial energy have been consumed on inefficient processes such as cooling, heating, pressing etc. in all over the Europe [7]. Therefore, the improvements made on production methods affects the sustainability of production at a large scale.

In this study, the scheduling problem and the due date assignment problem are integrated to make production planning considering environmental issues. Job shops consisting of more than one job, and machine are studied in the scheduling problem. It is assumed that there is single route for each job. In due date assignment phase, environmental friendly customers are also considered, which are manufacturing products in a proper way to protect environment. Each job in an organization can be classified as a customer. The weighting of the jobs is not done by only considering the single criteria as it is done in the traditional scheduling problems. Also, other criteria are used to calculate weights for a job. In the literature, there are many studies which have given weights to the jobs according to different criteria. In 2000, Agnetis et al. carried out the weighting of the jobs according to the amount of work in the workshop. Besides, they have tried to minimize the completion times and the number of jobs delayed [8].

Furthermore, integrated process planning and scheduling problem (IPPS) is also a new trend topic in terms of decreasing energy consumption in a manufacturing process. Zhang et al. have conducted a machine scheduling system to save energy in manufacturing system [9]. In this study, the energy consumption of machines and equipment is modeled as Therblig base in the process of manufacturing. In IPPS, process planning, and scheduling functions are integrated with alternative process plans. It has resulted in higher efficiency in energy saving. First study on IPPS was made by Wilhelm and Shin. They conducted a study to use production sources in an efficient way using alternative operations in 1985 [10]. Before studies on IPPS, process planning, and scheduling have been taken separately like a one function. Only scheduling functions are classified as NP-Hard problem. So, it is almost impossible to find optimal results in real applications for IPPS [11]. That is why, there are many studies on IPPS using meta-heuristic approaches such as genetic algorithm [12]–[16], simulated annealing [12], taboo search [17], particle swarm optimization [18], [19], agent-based [20], [21] and ant colony optimization [22].

Other integration problem is the scheduling with due date assignment problem (SWDDA). Basic principle of a just-in-time (JIT) philosophy is to minimize the unnecessary costs in production and to ensure a job is to be completed on its time. It is advised to finish products as close as possible to the due date in JIT. If an organization can schedule its production on the due dates which are reasonable, it will have optimum capacity planning. Using resources in an efficient way, may prevent labor cost and unnecessary energy consumption. The completion time of jobs before their due date could lead to an increase in energy costs and a decrease in customer satisfaction and customer loss. Integrated systems are determined by considering the scheduling and due date assignment together to avoid inefficient production plan. Some earlier studies reported that it was possible to find the optimal due dates and optimal sequences of jobs using different heuristic algorithms [8]–[16]. The objective of these studies is to minimize the cost related to due date assignment and scheduling function. Besides, some recent studies on SWDDA can be listed as; [17]–[36].

The remainder of the paper is organized as follows. In Section 2 modelling integrated production plan is discussed and the data used for the problem is described. Results of the schedules are given in Section 3. Section 4 includes conclusions and the discussing part of the study.

2. Materials and Method

Random Search (RS), Simulated Annealing (SA) and their hybrid is used in this study. Ordinary solution indicates the initially generated random solution.

Random Search (RS): RS uses new random solutions at each iteration. It has the advantage of fast improvement in the beginning of the iterations. Later rate of improvement quickly reduces.

Simulated Annealing (SA): SA used to solve large scale optimization problems, which was developed by Kirkpatrick et al. [52] in 1983. It is used in many problems in numerous discipline especially global extremum is searched within the many local extrema [53].

Random and Simulated Annealing (RS/SA): Random search was combined with SA and this hybrid method is utilized. Initial 5% of iterations are made with random search and rest of the iterations are made with SA. It is aimed to take advantage of wide search capability of random search, and more focused search capability of SA to obtain better solutions. Random search scans the solution space to faster and better only at the very beginning. Later SA focuses this solutions to get better ones.

As scheduling rules WATC (Weighted Apparent Tardiness Cost), ATC (Apparent Tardiness Cost) and SIRO (Service in random order) rules are utilized throughout the study. As due date assignment rules WPPW (Weighted process plus wait), PPW (Process plus wait) and RDM (Random) rules are applied. Rules for Scheduling and Due date assignment are explained in Appendix A and B respectively.

For the solution of the integrated problem a program is coded in C++ which performs Random Search, Simulated Annealing and Hybrid Simulated Annealing algorithms. Initially jobs are given proper due-dates by using WPPW, PPW or RND due-date assignment techniques and later jobs are scheduled according to WATC, ATC or SIRO rules and performance of the solution is calculated. After that in every iteration performance measure is tried to be improved by using RS, SA or RS/SA techniques.
Four different integration levels are utilized, which are SIRO-RDM, WATC-RDM, SIRO-WPPW, WATC-WPPW, and for the full integration level the combination ATC-PPW is also tested for unweighted customer case.
SIRO-RDM: There is no integration in this level. Jobs are scheduled according to service in random order rule and due dates are assigned randomly.
WATC-RDM: WATC scheduling rule is integrated with process plan selection. Due dates are still randomly assigned.
SIRO-WPPW: WPPW weighted due date assignment rule is used to determine due dates in this combination. On the other hand scheduling is made with service in random order rule.
WATC-WPPW: Process planning is integrated with WATC weighted scheduling and WPPW weighted due date assignment in this integration level. This s the best level and full integration level of the problem. Here weights of the customers were also taken into account.
ATC-PPW: This level is same as the WATC-WPPW method except customers are not weighted with their environmental manner. This combination is given to compare solutions, thus observing the effect of weighting customers.
Eight different shop floors with varying size are studied. Smallest shop floor has 5 machines and 25 jobs. There are 5 operations in each route. Processing time of each operation practically changes in between 1 and 30 minutes according to formula ⌊(12+z*6)⌋.
Largest shop floor has 10 machines, 200 jobs and same number of operations in each route as in smallest shop floor. Processing times are same as in other shop floors. Characteristics of each shop floor are listed at Table 1.

Table 1. Shop floors

Shop Floor	1	2	3	4	5	6	7	8
# of machines	5	5	5	5	10	10	10	10
# of Jobs	25	50	75	100	125	150	175	200
Processing Times	$\lfloor(12 + z * 6)\rfloor$							
# of op. per job	5							

3. Results

Everyone must take responsibility to preserve the environment as our world has limited resources. In this study customers are prioritized in terms of their attitudes towards preserving the environment. Comparison of twenty solution combinations for all the shop floors are given in Table 2. Results of weighted and unweighted fully integrated level of all shop floors are given in Fig. 1-8. Obtained results indicate that weighting the customers according to their environmental consciousness has a positive effect on schedule in all eight shop floors. CPU time of programs are under one second for small shop floors and under one minute for largest shop floors.

Table 2. Comparison of twenty solution combinations for all of the shop floors

Level of Integration	Approaches	Shop Floor 1			Shop Floor 2			Shop Floor 3			Shop Floor 4			Shop Floor 5			Shop Floor 6			Shop Floor 7			Shop Floor 8		
		Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst
SIRO-RDM	OS	287	287	287	848	848	848	1689	1689	1689	3028	3028	3028	2617	2617	2617	3704	3704	3704	4730	4730	4730	6344	6344	6344
	RS	258	259	260	723	731	737	1491	1516	1525	2722	2759	2787	2242	2286	2306	3171	3260	3291	4194	4272	4308	5658	5762	5805
	SA	263	266	269	810	824	830	1613	1662	1680	2956	2986	3013	2469	2536	2560	3544	3572	3591	4557	4603	4626	6133	6184	6225
	RS/SA	258	267	270	796	818	829	1597	1650	1673	2922	2978	2998	2512	2536	2555	3452	3557	3590	4536	4579	4611	6155	6179	6210
WATC-RDM	OS	246	246	246	645	645	645	1221	1221	1221	2203	2203	2203	1916	1916	1916	2649	2649	2649	3299	3299	3299	4544	4544	4544
	RS	257	264	270	656	688	712	1271	1288	1305	2233	2256	2274	1923	1981	2014	2623	2697	2736	3326	3385	3423	4589	4629	4667
	SA	246	247	250	645	651	657	1221	1235	1246	2203	2217	2226	1916	1946	1978	2649	2658	2672	3299	3313	3332	4544	4570	4598
	RS/SA	246	247	250	645	651	657	1221	1235	1246	2203	2217	2226	1916	1946	1978	2649	2658	2672	3299	3313	3332	4544	4570	4598
SIRO-WPPW	OS	275	275	275	907	907	907	1771	1771	1771	3031	3031	3031	2676	2676	2676	3638	3638	3638	4724	4724	4724	6258	6258	6258
	RS	258	270	275	812	824	835	1622	1663	1691	2831	2934	2973	2420	2462	2507	3439	3479	3520	4385	4464	4513	5894	6003	6082
	SA	265	273	276	789	804	812	1658	1668	1674	2891	2927	2945	2379	2437	2469	3440	3487	3517	4278	4409	4473	5913	5949	5986
	RS/SA	254	266	274	773	800	811	1567	1647	1684	2861	2932	2964	2429	2453	2465	3388	3492	3529	4439	4485	4516	5979	6047	6083
WATC-WPPW	OS	246	246	246	640	640	640	1217	1217	1217	2174	2174	2174	1821	1821	1821	2537	2537	2537	3133	3133	3133	4401	4401	4401
	RS	221	235	241	613	626	639	1180	1199	1217	2093	2139	2169	1699	1754	1818	2365	2438	2532	2921	3019	3133	4164	4280	4401
	SA	221	236	246	613	626	639	1180	1203	1222	2093	2139	2169	1699	1767	1835	2365	2455	2537	2921	3057	3141	4164	4300	4402
	RS/SA	221	237	246	613	631	647	1180	1199	1217	2093	2139	2169	1699	1754	1818	2365	2447	2535	2921	3038	3138	4164	4300	4402
ATC-PPW	OS	253	253	253	733	733	733	1459	1459	1459	2574	2574	2574	2120	2120	2120	2913	2913	2913	3766	3766	3766	5119	5119	5119
	RS	250	255	258	707	728	743	1423	1451	1466	2533	2560	2580	2080	2114	2166	2837	2893	2962	3693	3755	3830	5015	5088	5170
	SA	250	262	283	707	728	743	1423	1462	1513	2538	2576	2636	2080	2132	2213	2837	2909	2977	3693	3778	3885	5015	5109	5208
	RS/SA	251	256	260	707	739	768	1423	1468	1515	2533	2592	2655	2080	2148	2232	2837	2932	3028	3693	3793	3885	5015	5143	5260

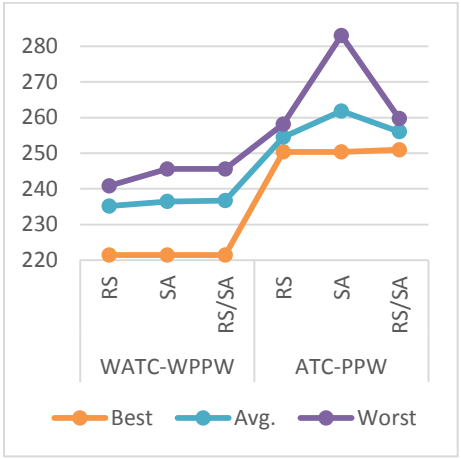

Figure 1. Result of shop floor 1 (25x5)

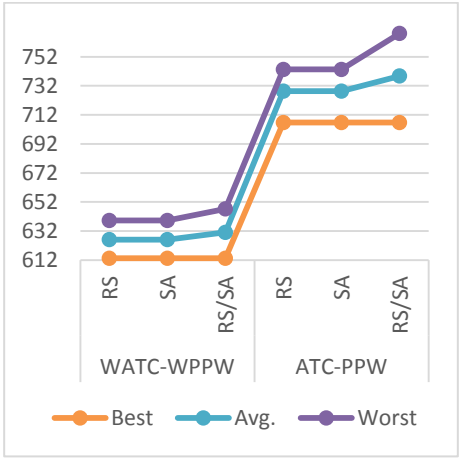

Figure 2. Result of shop floor 2 (50x5)

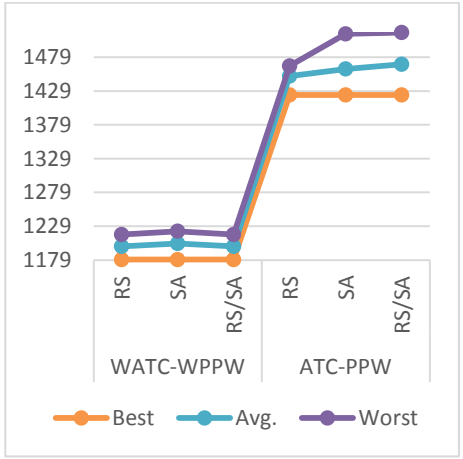

Figure 3. Result of shop floor 3 (75x5)

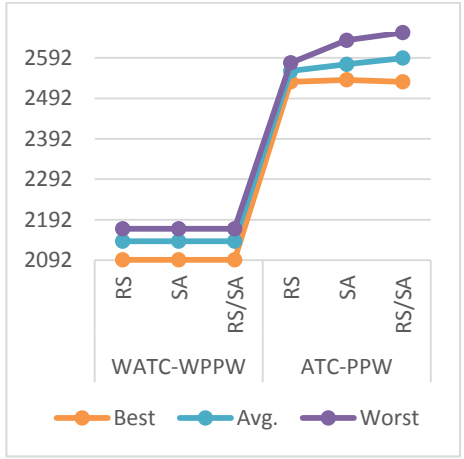

Figure 4. Result of shop floor 4 (100x5)

Although as integration levels increases better schedules are obtained, weighting the customers are much more improved the solution. Random Search, Simulated Annealing and their hybrid gave close results. Ordinary solutions are worst compared the search methods. As they are not given in figures for readability.

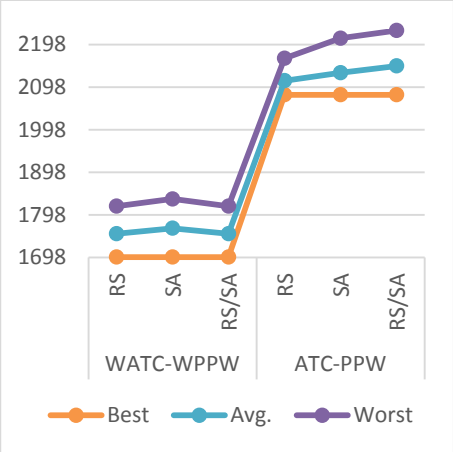

Figure 5. Result of shop floor 5 (125x10)

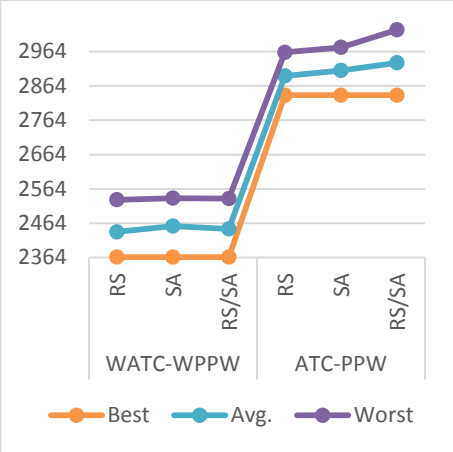

Figure 6. Result of shop floor 6 (150x10)

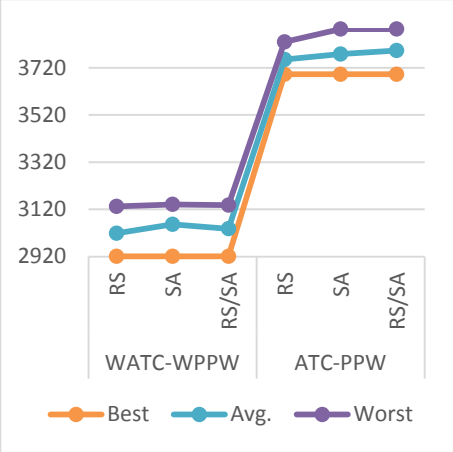

Figure 7. Result of shop floor 7 (175x10)

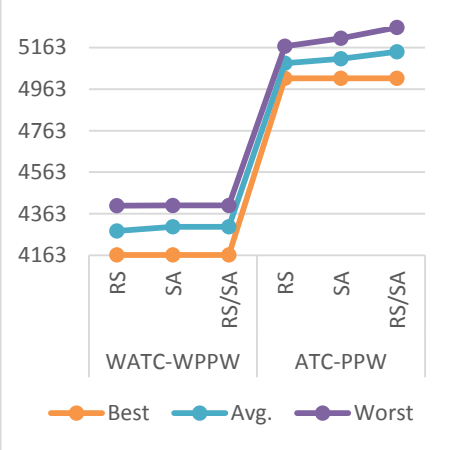

Figure 8. Result of shop floor 8 (200x10)

It has been seen that the range of change is decreases as the integration level increases. Thus, more integrated solutions gave similar results independently of method used. It is also noteworthy that RS has minimum values amongst worst solutions.

Conclusions

In this study scheduling with due-date assignment problem is studied for environmentally weighted customers. Step by step scheduling and due-date assignment functions are integrated. Initially SIRO scheduling and RDM due-date assignment combinations are tested and as expected this level found as the poorest integration level. Later WATC dispatching is introduced to the problem and integrating scheduling with the problem is found useful. After that WPPW is integrated with the problem but this time jobs or services are scheduled according to SIRO rule. Finally WATC scheduling and WPPW due-date assignment rules are integrated and full integrated level is tested and found as the best level of integration.

For the fully integrated level ATC scheduling and PPW due-date assignment integration is also tested where weights of the customers are not taken into account. WATC-WPPW integration is found much better compared to the ATC-PPW integration levels and results can be found in the Section 3 where the results are discussed. According to the results it is much better to schedule customers according to environmentally given weights.

If it is desired to increase environmentally sensitive people, those customers should be rewarded, and those who are not sensitive should be punished. Jobs and services should be weighted according to environmental criteria to raise awareness for environment.

Appendix A: Due-Date Assignment Rules

WPPW (Weighted Process Plus Wait) →Due = $q_x*w_1 + w_2*k_x*TPT$ (w_1, w_2 is determined according to weights) $q_x = q_1$, q_2 or q_3 $q_1=0.5*P_{avg}$, $q_2=P_{avg}$, $q_3=1.5*P_{avg}$, $k_x=1,2,3$

PPW (Process Plus wait) →Due = $q_x + k_x*TPT$ where $q_x = q_1$, q_2 or q_3 $q_1=0.5*P_{avg}$, $q_2=P_{avg}$, $q_3=1.5*P_{avg}$, $k_x=1,2,3$

RDM (Random Due Assignment) →Due = $N \sim (3*P_{avg}, (P_{avg})^2)$

TPT = Total Processing Time

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

Appendix B: Dispatching Rules

WATC (Weighted Apparent Tardiness Cost): It is a hybrid of MS (Minimum Slack First) and SPT (Shortest Processing Time First) dispatching rules where priority index is calculated as follows.

$I_j(t) = w_j/p_j*exp(-max(d_j-p_j-t,0)/K*P_{avg})$ where

$I_j(t)$ is priority index

p_j is j^{th} job processing time

$max(d_j-p_j-t,0)$ is j^{th} job slack

K is scaling parameter

P_{avg} is average processing time of the jobs

ATC: (Apparent Tardiness Cost) According to ATC rule priority index is calculated as follows

$I_j(t) = 1/p_j*exp(-max(d_j-p_j-t,0)/K*P_{avg})$

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

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