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Hybrid Evolutionary Strategy and Simulated Annealing Algorithms for Integrated Process Planning, Scheduling and Due-Date Assignment Problem

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Abstract

Although integrated process planning and scheduling (IPPS) problem is studied extensively as scheduling with due-date assignment problem (SWDDA) in the literature, there are only a few studies on integration of these three manufacturing functions which are process planning, scheduling, and due-date assignment. Since outputs of upper stream functions effect downstream functions and higher integration gives a better global performance, it is better to integrate these three functions. In this study integration of process planning and earliest due-date scheduling (EDD) with due-date assignment is studied using hybrid evolutionary strategies (RS/ES) and hybrid simulated annealing algorithms (RS/SA). Ordinary solutions (OS), random search (RS) solutions, evolutionary strategies (ES) solutions, and simulated annealing (SA) solutions are compared with each other and hybrid solutions of ES and SA, with RS. According to the results, higher integration found better and best results are obtained with the highest integration level. ES and SA methods gave better results compared to the RS and OS, and RS/ES and RS/SA techniques were found promising search techniques.

Keywords: Process planning, scheduling, due-date assignment, hybrid evolutionary strategies, hybrid simulated annealing, random search

1. INTRODUCTION

Process planning, scheduling, and due-date assignment are three primary manufacturing functions in a job shop environment, which directly affect each other. Integration is a necessity to improve overall performance. There are many studies on integration of the first pair (Integrated Process Planning and Scheduling - IPPS) and second pair (Scheduling With Due-Date Assignment - SWDDA) of these functions. However, there are a few studies on integration of all three functions (Integrated Process Planning, Scheduling, and Due-Date Assignment - IPPSDDA).

There are comprehensive literature surveys on IPPS problem such as Tan and Khosnevis [1], Li et al. [2] and Phanden et al. [3]. As an example of studies on IPPS problem Morad and Zalzala [4], Tan and Khoshnevis [5], Guo et al. [6], Baykasoğlu ve Özbakır [7], Leung et al. [8], Phanden et al. [9], Zhang and Wong [10] can be given.

Due-dates can be determined internally in which best dates can be investigated or externally in which they cannot be changed. There are two aspects of determining due-dates which are delivery reliability and speed [11]. Delivery reliability is an indicator that shows consistency in meeting orders as promised. Delivery speed is an ability to deliver orders with short lead times.

A comprehensive literature survey on SWDDA can be found in Gordon et al. [12]. Recent SWDDA studies can be given as Yin et al. [13–15], Iranpoor et al. [16]. Following works can be given as studies on Scheduling With Due-Window Assignment (SWDWA) problem; and Yang et al. [17]. Some

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of the works on the IPPSDDA problem can be given as Demir and Taskin [18], Demir and Erden [19]–[21], [21], [22].

The main focus of scheduling problems involves due-dates. A job is expected to be finished before its due-date in a conventional production system. Unlike this, in Just in Time (JIT) production system a job is to be finished exactly on its due-date. Instead of assigning due-dates, a due window is tried to be assigned in recent studies in which research is shifted from SWDDA to SWDWA.

It is not desired to deliver orders later than its due-date. On the other hand, it is also not desired to produce early due to working capital and inventory holding costs. In order to improve performance measure earliness, tardiness and due-date related costs are all penalized in this study.

Merely, scheduling function is in the NP-Hard problem class. An integrated problem is far more difficult to solve. Exact solutions can be found for small problems but as problem size increases it is not possible to find exact solutions in a reasonable time. At this point heuristic methods are more suitable.

Planning is a timely decision that has to be determined in a certain time, otherwise, there is no value of a plan which is no longer valid. To overcome this problem instead of using exact solution methods heuristics are indeed very useful. In this research evolutionary strategies (ES), simulated annealing (SA) and their random hybrids (RS/ES and RS/SA) are utilized. Results of these meta-heuristics are compared with each other and also compared with random search (RS) and initial ordinary solution (OS).

The remaining of this paper is organized as follows: definition of the problem is given in section 2, solution methods and integration levels are given in section 3, experimentation is given in section 4, and the conclusion is given in the last section.

2. PROBLEM DEFINITION

In this study integration of process planning, scheduling and due-date assignment functions are considered. Problem is represented as a chromosome with (n+2) genes given in Figure 1. First two genes are used to represent due-date assignment and dispatching rules, respectively. Rest of the genes (n) represents the route of jobs. Effect of first two genes on a solution is higher than other genes which affects route of a single job. Thus, they have been found as dominant genes and given higher probability to be selected by mutation operator.

Eight different sized shop floors are considered which are given in Table 1. The first four problems have five routes for each job to select from, the last four problems have three routes for each job. As an example, the first shop floor has 5 machines, 25 jobs, and 10 operations for each job.

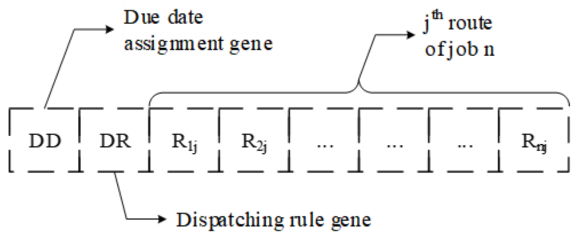

Figure 1. Sample chromosome

Table 1. Shop Floors

Shop floor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
# of machines	5	10	15	20	25	30	35	40
# of jobs	25	50	75	100	125	150	175	200
# of routes	5				3			
# of operations per job	10							

Three types of machine groups are defined to represent the technology and capability of machines. High technology machines are relatively fast, average machines are faster than old ones, and old machines are the slowest. The processing time of each operation is calculated according to the machine group it belongs given in Table 2. For example, processing times of machine group 1 are calculated according to normal distribution with a mean of 10 and a standard deviation of 5. Each route has different probabilities to choose machine groups which are also given in Table 2. For example, route 1 has probabilities of 0.8, 0.1, and 0.1 to select machine groups 1, 2, and 3, respectively for shop floors 1, 2, 3, and 4.

Table 2. Probability of machine group selection based on routes

Shop Floor	**Machine Group**	**Processing Times**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**
1, 2, 3, 4	**1**	$\lfloor(10+z*5)\rfloor$	0.8	0.6	0.33	0.2	0.1
	2	$\lfloor(12+z*6)\rfloor$	0.1	0.25	0.33	0.3	0.2
	3	$\lfloor(14+z*7)\rfloor$	0.1	0.15	0.34	0.5	0.7
5, 6, 7, 8	**1**	$\lfloor(10+z*5)\rfloor$	0.7	0.33	0.2	N/A	N/A
	2	$\lfloor(12+z*6)\rfloor$	0.2	0.33	0.2	N/A	N/A
	3	$\lfloor(14+z*7)\rfloor$	0.1	0.34	0.6	N/A	N/A
N/A: Not available							

Due-date assignment is made with the first gene according to the RDM and DUE rules given in Table 3 and explained in Appendix A. DUE rule has four different options, which are TWK, SLK, PPW, and NOP. With different multipliers and constants, 18 different rules are used in DUE.

Table 3. Due-date assignment rules

Method	**Multiplier (twk_x, p_x)**	**Constant (q_x)**	**Rule no**
Total Work (TWK)	$twk_x = twk_1, twk_2, twk_3$		1, 2, 3
Slack (SLK)		$q_x = q_1, q_2, q_3$	4, 5, 6
Processing Plus Wait (PPW)	$twk_x = twk_1, twk_2, twk_3$	$q_x = q_1, q_2, q_3$	7, 8, 9, 10, 11, 12, 13, 14, 15
Number of Operations (NOP)	$p_x = p_1, p_2, p_3$		16, 17, 18
Random Due Assign (RDM)			19

Dispatching is made with the second gene according to Earliest Due-Date (EDD) and Service in Random order (SIRO) rules. A job among waiting jobs is selected randomly to be processed in SIRO.

A working day is assumed as one shift with 8 hours (480 minutes). Tardiness, earliness and due-dates are penalized as it contributes to making more realistic plans. The performance measure is to minimize the costs resulting from these. The proportion of these costs are penalized with different constants as given in Eq. (1), (2), and (3). Tardiness and earliness are also penalized with a fixed cost. Tardiness is punished more than others. The penalty of a job and the total penalty is given in Eq. (4) and (5), respectively.

$$Penalty\ for\ Due-Dates\ (PD) = 8 * \left(\frac{DueDate}{480}\right) \quad (1)$$

$$Penalty\ for\ \text{earliness (PE)} = 5 + 4 * \left(\frac{\text{E}}{480}\right) \quad (2)$$

$$Penalty\ for\ tardiness\ (PT) = 10 + 12 * \left(\frac{T}{480}\right) \quad (3)$$

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

$$Total\ Penalty = \sum_j Penalty(j) \quad (5)$$

3. SOLUTION METHODS AND INTEGRATION LEVELS

OS, RS, ES, SA, RS/ES, and RS/SA methods are used to solve the IPPSDDA problem. To be fair among different methods their population size and iteration numbers are equalized. A number of iterations applied are given in Table 4.

Table 4. Number of iterations applied

	RS	SA	RS-SA Hybrid		ES		RS-ES Hybrid
SF	**RS Iter.**	**SA Iter.**	**RS Iter.**	**SA Iter.**	**ES Iter.**	**RS Iter.**	**ES Iter.**
1,2	200	2000	100	1900	200	10	190
3,4	150	1500	75	1425	150	8	142
5,6	100	1000	50	950	100	5	95
7,8	50	500	25	475	50	3	47

Solution methods are shortly explained as follows:

Ordinary Solution (OS): Randomly produced initial chromosome in which one of the random chromosomes generated in the beginning is an ordinary solution. This is the worse solution method compared to the other meta-heuristic methods.

Random Search (RS): RS is an undirected search method that generates 10 new chromosomes randomly in each iteration. The best 10 chromosomes are selected from the new population and the previous population. RS is better than OS. Marginal improvements are very high in the beginning but sharply reduces as the iterations go on.

Simulated Annealing (SA): SA is utilized in this study with a single chromosome in each iteration. Thus, more iterations are made with SA to be fair with other methods.

Hybrid Simulated Annealing (RS/SA): With this hybrid method initial marginal benefits of undirected RS is combined with a directed search of SA. In this method, 5% of total iterations are made with RS and the rest of the iterations are made with SA.

Evolutionary Strategies (ES): ES is an optimization method based on the ideas of evolution. ES differs from the genetic algorithm (GA) by operator types. GA uses both mutation and crossover operators, on the other hand, ES only uses mutation operator.

Hybrid Evolutionary Strategies (RS/ES): With this hybrid method initial marginal benefits of undirected RS is combined with a directed search of ES. In this method, 5% of total iterations are made with RS and the rest of the iterations are made with ES.

Different integration levels of three production functions are utilized. There is no integration in the SIRO-RDM level. Process plan selection is made without considering scheduling and due-date assignment. Scheduling of jobs made randomly as due-dates. EDD scheduling with process plan selection is integrated in EDD-RDM level. But due-dates are still randomly determined. In SIRO-DUE level due-date assignment is integrated to process planning however jobs are scheduled randomly. EDD-DUE is the fully integrated level in which process planning is integrated with EDD dispatching and due-date assignment.

4. EXPERIMENTATION

IPPSDDA problem is coded with the C++ language. Experiments are executed in a desktop computer with 64-bit Windows 10 operating system on a 3.1 GHz Intel i5-2400 processor and 4 GB ram. Problems are compiled with Borland C++ 5.02 compiler. Mean CPU times of shop floors 1 to 8 are 14, 82, 163, 312, 233, 348, 239, and 318 seconds, respectively.

There are 6 different methods and 4 different integration combinations, a total of 24 different solution combinations are calculated for each shop floor and summarized in Table 5 and Table 6. Results of highest integration combination (EDD-DUE) of shop floors 1-4 are given in Figure 2 (a,b,c,d) and shop floors 5-8 are given in Figure 3 (a,b,c,d), respectively. Similar conclusions can be made for different shop floors according to results. The performance of solutions gets better as the integration level increases. Search methods are superior compared to ordinary solutions. RS is the worst search solution compared to other methods. ES and RS/ES methods are the best amongst all methods.

Table 5. Comparison of 24 solution combinations for the shop floors 1-4

Level of Integration (Combination)	Approaches	Shop Floor 1			Shop Floor 2			Shop Floor 3			Shop Floor 4		
		Best	**Avg.**	**Worst**	**Best**	**Avg.**	**Worst**	**Best**	**Avg.**	**Worst**	**Best**	**Avg.**	**Worst**
SIRO-RDM	**OS**	319	319	319	646	646	646	983	983	983	1309	1309	1309
	RS	265	272	276	586	598	606	890	899	906	1269	1278	1285
	SA	269	273	275	543	553	557	853	862	870	1226	1234	1240
	RS/SA	253	256	258	562	566	568	863	873	880	1223	1234	1238
	ES	246	252	254	546	552	556	833	842	846	1197	1204	1210
	RS/ES	240	248	251	545	548	551	837	851	857	1207	1216	1222
EDD-RDM	**OS**	269	269	269	558	558	558	835	835	835	1187	1187	1187
	RS	219	228	234	513	539	547	788	796	802	1156	1172	1183
	SA	197	201	204	472	482	486	753	758	762	1104	1115	1123
	RS/SA	198	203	205	463	480	484	746	751	755	1089	1102	1105
	ES	189	194	196	469	473	476	719	727	734	1038	1060	1068
	RS/ES	201	204	207	446	454	462	716	722	725	1076	1080	1083
SIRO-DUE	**OS**	347	347	347	730	730	730	1087	1087	1087	1504	1504	1504
	RS	258	264	270	559	581	592	825	845	859	1182	1213	1227
	SA	243	249	252	512	524	530	804	814	821	1138	1148	1154
	RS/SA	238	242	245	510	526	533	802	815	821	1128	1144	1149
	ES	221	232	237	498	510	514	776	781	789	1100	1115	1122
	RS/ES	231	236	239	507	510	513	767	779	786	1120	1132	1140
EDD-DUE	**OS**	300	300	300	581	581	581	869	869	869	1272	1272	1272
	RS	230	235	239	507	512	514	730	749	758	1064	1078	1083
	SA	204	208	210	462	467	471	693	702	707	1005	1016	1021
	RS/SA	210	215	217	449	460	465	667	685	689	1038	1041	1043
	ES	206	210	212	441	448	451	672	680	683	987	993	997
	RS/ES	205	208	210	434	440	443	665	671	673	976	985	989

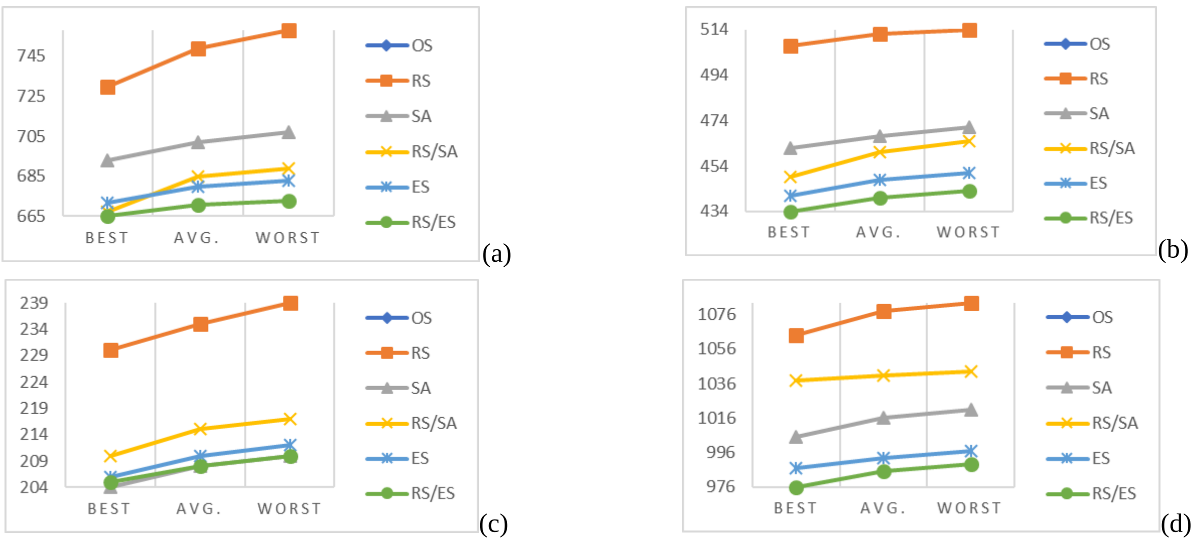

Figure 2. Performance comparisons of shop floors 1-4

Table 6. Comparison of 24 solution combinations for the shop floors 5-8

Level of Integration (Combination)	Approaches	Shop Floor 5			Shop Floor 6			Shop Floor 7			Shop Floor 8		
		Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst	Best	Avg.	Worst
SIRO-RDM	OS	1831	1831	1831	2110	2110	2110	2154	2154	2154	2783	2783	2783
	RS	1590	1632	1644	1914	1930	1944	2108	2154	2171	2659	2707	2719
	SA	1608	1616	1624	1848	1866	1876	2104	2123	2138	2598	2618	2628
	RS/SA	1562	1575	1582	1864	1879	1888	2070	2089	2105	2613	2626	2637
	ES	1556	1569	1577	1840	1858	1867	2067	2092	2101	2585	2600	2606
	RS/ES	1538	1558	1566	1860	1877	1884	2060	2085	2092	2624	2628	2635
EDD-RDM	OS	1622	1622	1622	1956	1956	1956	2039	2039	2039	2495	2495	2495
	RS	1407	1423	1431	1713	1732	1745	1970	1985	1991	2453	2470	2481
	SA	1332	1356	1366	1638	1655	1664	1879	1905	1915	2371	2387	2396
	RS/SA	1353	1362	1366	1675	1683	1688	1901	1922	1936	2358	2376	2387
	ES	1313	1319	1323	1610	1620	1624	1912	1925	1935	2362	2379	2387
	RS/ES	1310	1333	1341	1614	1630	1636	1931	1936	1941	2332	2357	2367
SIRO-DUE	OS	2040	2040	2040	2344	2344	2344	2490	2490	2490	3124	3124	3124
	RS	1479	1497	1514	1747	1771	1794	1975	2028	2059	2530	2578	2610
	SA	1389	1410	1427	1713	1748	1764	1894	1932	1947	2390	2439	2459
	RS/SA	1386	1414	1425	1687	1724	1744	1951	1974	1991	2427	2442	2455
	ES	1405	1418	1425	1683	1694	1705	1910	1923	1930	2437	2478	2499
	RS/ES	1407	1414	1419	1675	1695	1704	1925	1937	1945	2399	2431	2446
EDD-DUE	OS	1659	1659	1659	1935	1935	1935	2078	2078	2078	2656	2656	2656
	RS	1283	1313	1325	1572	1595	1604	1774	1800	1818	2208	2261	2280
	SA	1236	1249	1257	1524	1544	1553	1730	1750	1761	2185	2203	2214
	RS/SA	1233	1251	1257	1516	1530	1536	1742	1758	1767	2148	2178	2197
	ES	1233	1244	1250	1504	1512	1516	1712	1722	1728	2147	2160	2170
	RS/ES	1239	1245	1249	1507	1510	1514	1712	1722	1729	2184	2197	2209

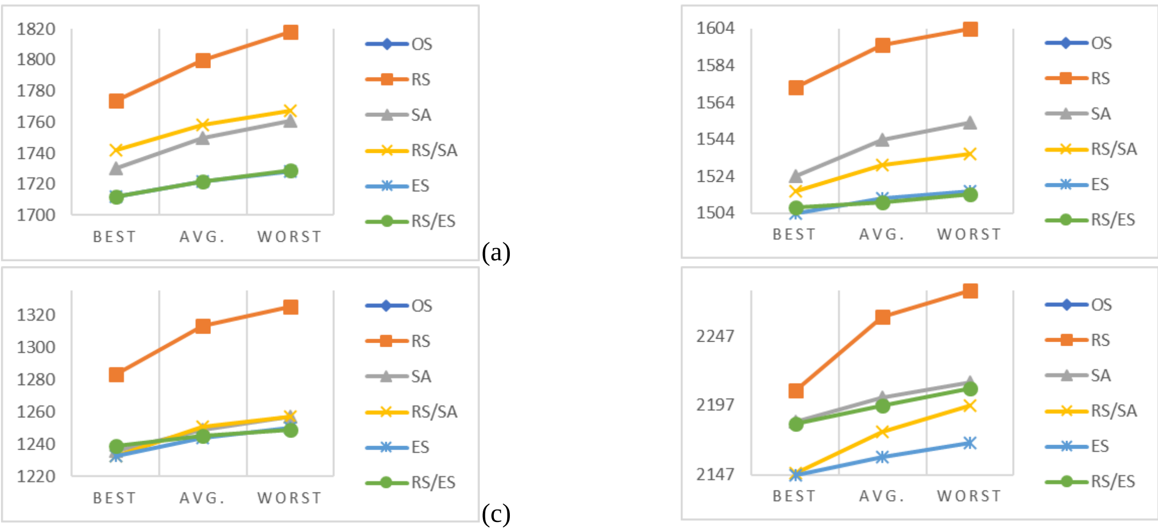

Figure 3. Performance comparisons of shop floors 5-8

5. CONCLUSIONS

Process planning, scheduling, and due-date assignment are three important production functions that are traditionally solved separately. IPPS and SWDDA are studied in the literature and there are numerous works on them. On the other hand, the integration of all three functions is a relatively new subject. In this study, these functions are integrated and solved concurrently with different solution methods in which contributed to global performance.

Four different integration levels are tested with six solution method on eight different sized shop floor and compared with each other. While the unintegrated solution has the worst performance, a fully integrated solution has the best performance as expected. Results also show that ES and RS/ES methods are best amongst others.

In the literature, studies are performed on IPPS and SWDDA and they only integrate two functions. But, in this study three functions are integrated to obtain higher global performance. The data set discussed in this study was created in a problem-specific structure and it was not right to compare with the data sets in the literature. As the studies on the integration of these three functions are performed more then there will be the possibility of benchmarking between studies.

Companies must find ways to survive in today's fierce competition. Using fewer resources to produce more qualified products is essential in this harsh environment. The results of this study encourage decision-makers to utilize their production functions as a whole and use suitable methods to solve them. The integration studies of manufacturing functions provide significant gains in terms of global optimization.

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