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SOLVING THE HYBRID FLOW SHOP SCHEDULING PROBLEM USING HEURISTIC ALGORITHMS[1]

Fatma Selen MADENOĞLU[2]

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ABSTRACT

A variant of the hybrid flow shop (HFS) problem considering missing operations, transportation times and sequence-dependent setup times is investigated. Heuristic algorithms along with dispatching rulesand dispatching rules are used to solve the given problem. The objective function is minimization makespan. The computational experimets are conducted to test the performance of the heuristic algoirthms and dispatching rules. In order to depict the effect of the factors: number of jobs, number of machines, number of production stages, level of missing operations on the result, the additiol experimentes are carried out. The result of NEH heuristic with SPTF rule outperformed other heuristics for the proposed HFS problems.

Keywords: *Combinatorial Optimization, Heuristics, Hybrid Flow Shop Scheduling*

Jel Codes: *M10, M11*

HİBRİT AKIŞ TİPİ ÇİZELGELEME PROBLEMİNİN SEZGİSEL ALGORITMALAR KULLANILARAK ÇÖZÜMÜ

ÖZ

Eksik operasyonlar, taşıma zamanı ve sıra-bağlı hazırlık süreleri dikkate alınarak hibrit akış tipi çizelgeleme probleminin bir çeşidi incelenmiştir. Gönderim kuralları ile birlikte sezgisel algoritmalar ve gönderim kuralları verilen sorunu çözmek için kullanılmıştır. Toplam tamamlanma zamanının en küçüklenmesi amaç fonksiyonudur. Hesaplamalı deneyler, sezgisel algoritmalar ve gönderme kurallarının performansını test etmek için yapılmıştır. Faktörlerin sonuca etkilerini göstermek için iş sayısı, makine sayısı, üretim aşaması sayısı, eksik operasyon oranların değişiminin incelendiği deneyler gerçekleştirilmiştir. Önerilen hibrit akış tipi çizelgeleme problemlerinde NEH'nin SPTF kuralı ile oluşturulan sezgisel algoritmanın sonucu diğer sezgisellerden daha iyi sonuç vermiştir.

Anahtar Kelimeler: *Kombinatoryal Optimizasyon, Sezgiseller, Hibrit Akış Tipi Üretim Çizelgeleme*

Jel Kodları: *M10, M11*

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[2] Asistant Prof. Dr., Abdullah Gul University, selen.madenoglu@agu.edu.tr https://orcid.org/0000-0002-5577-4471

1. INTRODUCTION

Flow shop scheduling problem has been widely investigated in the literature. Nowadays, to increase the capacity, to fulfill customer expectations, to increase flexibility, some firms duplicate the machines in some stages or all stages. As a result, there is a set of machines at some stages in flow shop environment and this production environment turn into a hybrid flow shop environment. The HFS problem can be classified to three parts depending on the types of machines in every stage. In the HFS problem with identical machines, the processing time of a operation for all machines in a stage is same. In the HFS problem with uniform machines, the processing time of a operation for different machines in a stage can be changed according to the speed adjustment. In the HFS problem with unrelated machines, the processing time of a operation for different machines in a stage is independent.

In this paper, HFSP with the identical parallel machines, sequence-dependent setup time, transportation time and missing operations is discussed. Makespan is objective function. Heuristic algorithms are used for the proposed problem and the computational experiments are conducted to compare the heuristics.

In Section 2, the related literature is discussed. The proposed problem is defined in Section 3. The heuristics are given in the Section 4. Section 5 describes the computational experiments. The conclusion is presented in section 6.

2. LITERATURE REVIEW

The HFS problem is not widely discussed and analysed in the literature. The research papers deal with the ordinary HFS problem. Gupta (1988) presented an approximate solution for HFS problem under only one machine and two stage. Linn and Zhang, (1999) reviewed the HFS problem and this paper presented some suggestions for future directions. Botta-Genoulaz (2000) studied six new heuristic to solve the HFS problem minimizing maximum lateness under precedence constraints and time lags. An artificial immune system were investigated by Engin and Döyen (2004) to tackle the HFS problem with makespan criterion. Zandieh, Ghomi, and Husseini (2006) used an immune algorithm to solve the HFS problem considering setup times. An improved ant colony algorithm was presented by Alaykýran, Engin and Döyen (2007) to solve the HFS problem under makespan minimazing objective. The branch and bound method used as a comparative method and the results showed that it was an effective algorithm for solving HFS problem. Janiak, Kozan, Lichtenstein and Oğuz (2007) studied the HFS problem with cost related criterion and proposed three constructive heuristic algorithm and three metaheuristic algorithm based on tabu search and simulated annealing algorithm. A mixed integer model and heuristics were developed by Ruiz, Şerifoğlu and Urlings (2008) to tackle the HFS problem with sequence dependen setup times, machine lags, precedence constraints and release dates. Gholami et al. (2009) used genetic algorithm to tackle the HFS problem under sequence dependent setup times and machine break downs constraint. Naderi et al. (2009) developed a simulated annealing algorithm to handle the HFS problem with sequence dependent setup times and transportation times under minimizing total completion time and total tardiness. Wang et al. (2010) presented a novel hybrid discrete differential evolution algorithm to solve the blocking flow shop scheduling problem under minimization objective. The results of this algorithm were better than the result of tabu search and hybrid differential evolution algorithm. Ribas, Leisten and Framinan (2010) reviewed the research papers published on HFS problem since 1995 and a new classified approach for HFS problem is presented. In addition to this new classification approach, these reassearch papers were classified considering the solution approach. Dugardin, Yalaoui and Amodeo (2010) discussed a reentrant HFS problem. They used a new multi-objective genetic algoirthm to solve this problem. The obtained results were compered with the results of NSGA2 algorithm, SPEA2 algorithm and exact method. The results of the proposed algorithm outperformed the others. Naderi, Ruiz, and Zandieh (2010) developed a dynamic dispatching rule and an iterated local search for the HFS problem with sequence-dependent setup times under makespan minimization objective. Ruiz and Vázquez-Rodríguez (2010) examined more than 200 research papers about HFS problem and its variants. They discussed exact, heuristic and metaheuristic methods to solve this problem. Mirsanei et al. (2011) proposed an improved simulated annealing algorithm for solving the HFS problem with sequence dependent setup times. Liao, Tjandradjaja and Chung (2012) presented a new hybridizing PSO with bottlenek heuristic for solving the HFS problem minimizing makespan. Zhu (2012) presented a polynomial time algorithm for solving the two centers HFS problem with transportation and batching. Luo et al. (2013) developed a new ant colony algorithm considering production efficiency and electric power cost. The performance of the proposed algoirthm outperfomed NSGA-II and SPEA2 algorithms. An improved cuckoo search algorithm was developed by Marichelvam, Prabaharan and Yang (2014) for the HFS problem. The performance of the proposed algorithm was better than the performance of the other metaheuristics. Kizilay et al. (2014) developed novel constructive heuristics and an IG algorithm for the HFS problem with makespan criterion. Fattahi et al. (2014) presented a branch and bound algoirthm for solving ths HFS problem with setup time and assembly operations. A mixed integer linear programming models and a novel hybrid PSO algorithm for the HFSP were developed by Naderi, Gohari, and Yazdani (2014). Li, Pan and Wang (2014) proposed a hybrid algorithm that combined the chemical reaction optimization algorithm and the estimation of distribution to solve the HFS problem underminimizing makespan objective. Zhong and Lv (2014) presented a fast heuristic for two centers HFSP with transportation time. A simulation optimization approach was presented by Lin and Chen (2015) to solve the HFS problem of a real-worl semiconductor back-end assembly facility. Lei (2015) presented a two-phase neighborhood search algorithm for solving the HFS problem with two agents. Komaki, Teymourian and Kayvanfar (2016) proposed heuristic and two metaheuristics for solving two stge flow shop scheduling problem. A mixed integer linear programming model, ant colony optimization with double pheromone and genetic algoirthm were proposed by Zabihzadeh and J. Rezaeian (2016) for solving the flexible flow shop scheduling problem with unrelated machines, the release time and the robotic transportation, under makespan criterion. Pan et al. (2017) proposed nine algorithms for the HFS problem with sequence dependent setup times. The discerete artificial bee colony optimization algorithm was selected the best among them. A modified migrating birds optimization algorithm was proposed by Zhang et al. (2017) to solve the HFS problem with lot streaming under minimizinf the total flow time objective. Varela et al. (2017) compared the performance of the parallel flow shop and the HFS problems. Dios et al. (2018) carried out the computational analysis to depict the hardness of the HFS problem with missing operations. In additon to this, they developed a set of heuristics for solving the HFS problem with missing operations. Li et al. (2018) proposed a hybrid energy-aware multi objective algorithm to tackle the HFS problem. The main aim of this paper was the HFS problem minimizing energy consumption and makespan simultaneously. The comparative experiments showed the effeciciency of the proposed algorithm. Moccellin et al. (2018) investigated heuristic algorithms with priority rules to solve the HFS problem with machine blocking and setup times. Hidri et al. (2018) studied exact procedures and a two phase's heuristic to solve the two-center HFS problem with transportation times. The computational results depicted the proposed procedures are very effective. Lee and Loong (2019) reviewed the research papers since 2000 about the flexible flow shop scheduling problem. The given the related literature provides that the HFS problem with missing operations, sequence-dependen setup times and transportation times considering its practical importance has not been discussed widely.

3. PROBLEM DESCRIPTION

A flow shop scheduling problem is one of the most populer and classical problem in scheduling literature. Firms add more than one machine to each production stage in the flow shop environment to improve the efficiency and increase the daily production rate. The new problem defined as hybrid flow shop scheduling (HFS) problem. Figure 1 shows the general representation of the HFS problem with *k* production stages. It's defined as follows: There is *n* jobs to be operated on a set of production stages ($k \geq 2$). Each production stages or machine centers includes a set of identical parallel machines (m_k) to perform same operation.

In this paper, a variant of the classical HFS problem is discussed with the following additional constraints: The anticipatory-sequence dependent setup times are separated from processing times. All machine in each stage is identical. In this proposed problem, the machine is not idle until the next job is available. The setup operations are considered according to previous job processed on this machine and the stage information, before one job is processed on the machine. Whenever the machine is idle, the setup operation can be operated. After the operation of a job is finished, this job is carried to other stage. The transportation time between stages is considered. Each machine processes the jobs only once. All jobs doesn't follow the same route. Some stages can be skipped and this results with missing operastions. There is unlimited buffer. Each operation of the job is asssigned to one machine. If this machine is unavailable, this job is put to the buffer. The operations of the jobs are operated by only one machine at each stage. The objective function is minimizing makespan. All jobs, machines are available to use at time zero.

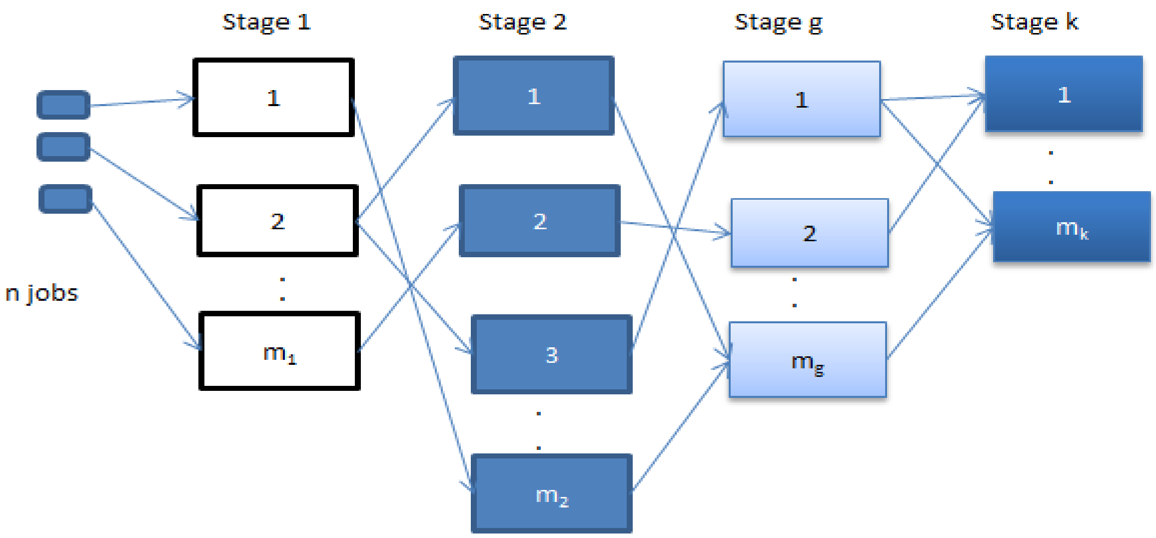

Figure 1. Hybrid Flow Shop Environment

Consider the instance with four jobs, three production stages, two machines per production stage. The processing times are presented in Table 1, the setup times are given in Table 2. Initial setup time for each machine is 5,10 time units, respectively. The transportation times are shown in Table 3. Makespan of a feasible solution for the given example is 172 time units. Figure 2 shows this feasible solution for the variant HFS problem.

Table 1. Processing Times For The Given Example

Job	Production stage		
	1	2	3
1	30	42	21
2	37	31	45
3	41	29	33
4	33	38	0

Table 2. Sequence-Dependent Setup Times For The Given Example

Job/Job	1	2	3	4
1	-	15	18	12
2	19	-	13	14
3	21	20	-	13
4	17	15	11	-

Table 3. Trasportation Times For The Given Example

Stage/Stage	1	2	3
1	-	5	10
2	-	-	5
3	-	-	-

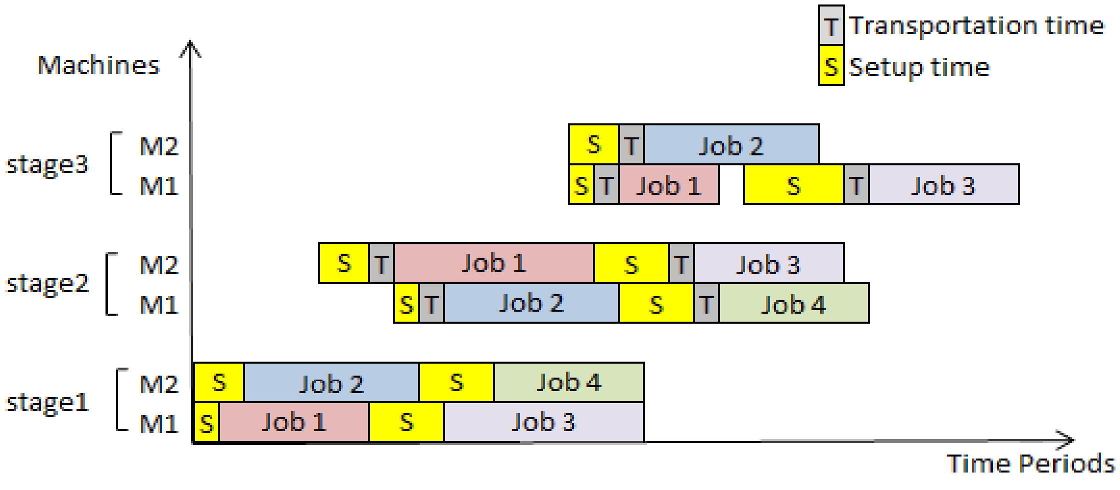

Figure 2. A Feasible Solution For The Given Example

4. HEURISTICS

The proposed variant HFS problem is NP-hard. In this paper, heuristic algorithms are used to settle feasible solution. NEH heuristic is the most efficient (Taillard,1990:65; Turner and Booth, 1987:75). Because of this reason, NEH heuristic is applied to the proposed problem. The four dispatching rules: shortest processing time (SPT), longest processing time (LPT), shortest processing time at the first stage (SPTF), longest processing time at the first stage (LPTF), weighted shortest processing time (SPTW), weighted longest processing time (LPTW) used to construct initial feasible solution of NEH heuristic.

5. COMPUTATIONAL EXPERIMENTS

In this section, the performance of the proposed heuristics are analysed using experimental studies. All configurations for experiments are deliberately designed according to the real situation.

5.1. Experimantal Design

In this section, in order to understand how the parameter value effects the performance of the proposed heuristics, the extensive experimental studies are conducted. The number of jobs analysed in this paper are 5, 10, 20, 30, 40, 50 jobs. The processing times are assumed to be drawn from a uniform distribution between 1 and 90. The values of the stage are three stages and seven stages. The number of parallel machines per stage is three and five machines. The sequence dependent setup times and transportation times are a uniform distribution 1 and 20, a uniform distribution 1 and 10, respectively. 0% and 20% are used as the percentage of missing operations. The relative percentage deviation (RPD) is used to evaluate the result:

$$RPD_h = \frac{C_{maxh} - C_{max}^{best}}{C_{max}^{best}} . 100$$

where RPD_h is the relative percentage deviation of heuristic h for an specific instance, C_{maxh} is the makespan obtained by heuristic h for that instance, C_{max}^{best} is the best makespan obtained by any heuristic in that instance. In addion to the *RPD*, is calculated as the number of times that a given rule results in the best solution divided by the number of test instances in a given instance class.

5.2. Results And Discussion

The parametres are grouped instances according to the parameter 'number of jobs (*n*)' to present the results in a summarized way. Table 4 shows the labels for each group. In Table 5, the computational results of the overall percent deviation of twelve heuristics for each level of missing operations are presented. The ranking of the heuristics according to ARPD are given in the Table 5. The results show us that there are three heuristics (NEH_SPTF, NEH_LPTW and SPTF) dominate the other nine.

Table 4. Tested Instance Classes

Class	Parameters $g/m_k/s/t/m_o$
C1	3 / 3 / U[1,20] / U[1,10] / %0
C2	3 / 3 / U[1,20] / U[1,10] / %20
C3	3 / 5 / U[1,20] / U[1,10] / %0
C4	3 / 5 / U[1,20] / U[1,10] / %20
C5	7 / 3 / U[1,20] / U[1,10]/ %0
C6	7 / 3 / U[1,20] / U[1,10] / %20
C7	7 / 5 / U[1,20] / U[1,10] / %0
C8	7 / 5 / U[1,20] / U[1,10] / %20

Table 5. Performance Of Heuristics

Ranking	0% Missing Operations		20% Missing Operations		All instances	
	Heuristic	ARPD	Heuristic	ARPD	Heuristic	ARPD
1	NEH_SPTF	1.38	NEH_SPTF	1.34	NEH_SPTF	1.36
2	NEH_LPTW	1.72	SPTF	4.75	NEH_LPTW	3.74
3	NEH_LPT	2.95	NEH_LPTW	5.70	NEH_LPT	5.21
4	LPTW	5.06	NEH_LPT	7.46	SPTF	5.27
5	SPTF	5.80	NEH_SPT	8.87	NEH_SPT	9.22
6	LPT	6.77	NEH_SPTW	8.91	LPTW	8.72
7	NEH_LPTF	8.81	LPTW	12.37	NEH_SPTW	9.30
8	NEH_SPT	9.57	LPT	12.38	LPT	9.58
9	NEH_SPTW	9.69	SPT	13.27	NEH_LPTF	12.32
10	LPTF	14.94	SPTW	15.65	SPT	14.27
11	SPT	15.08	NEH_LPTF	15.83	SPTW	15.52
12	SPTW	15.39	LPTF	21.86	LPTF	18.40

Figure 3 presents the results considering ARPD without missing operations. For problem instances with number of stages g=3, the heuristic NEH_SPTF has showed the best performance. The results obtained ARPD with missing operations are given in Figure 4. Figure 5 shows the results for all instances. Heuristic NEH_SPTF has achieved the best performance for all instances.

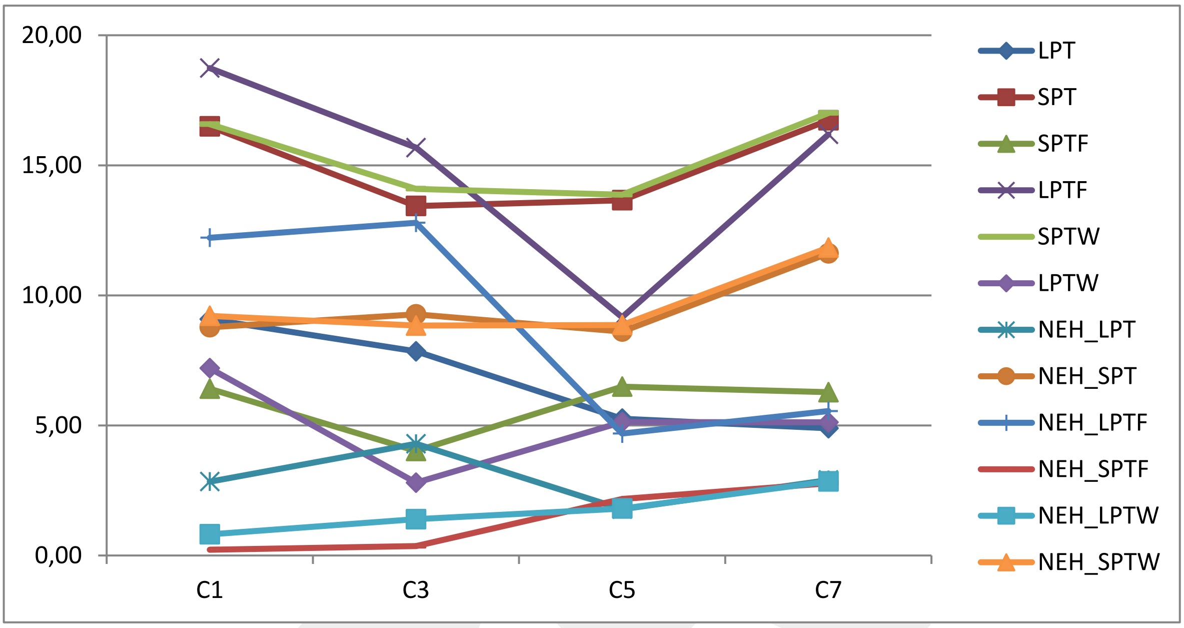

Figure 3. Comparison Of Average Percent Relative Deviation For Each Proposed Heuristics By Instance Category Without Missing Operations

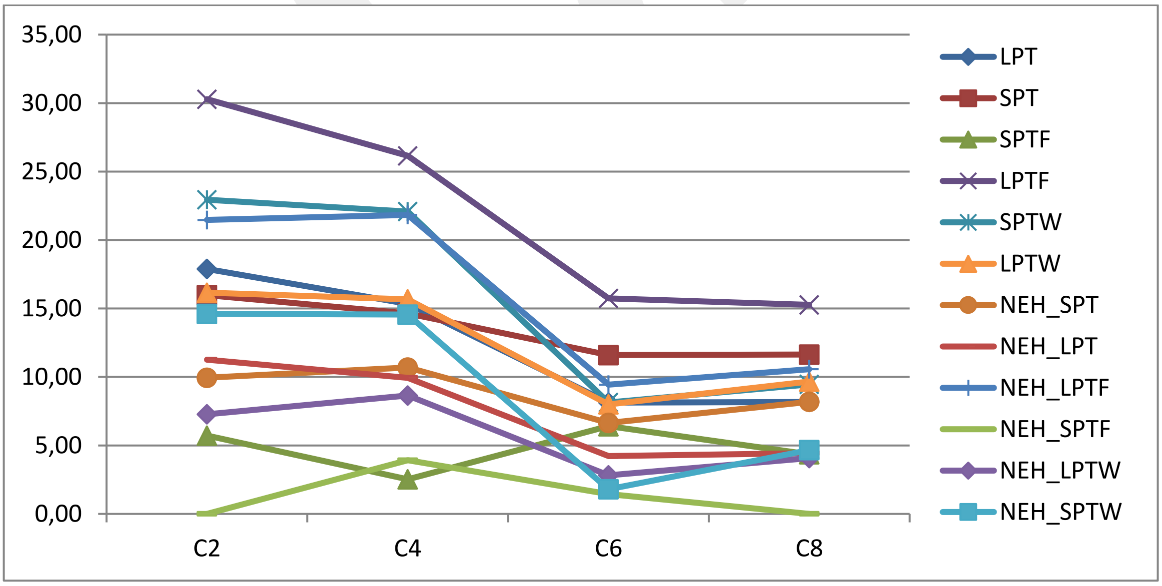

Figure 4. Comparison Of Average Percent Relative Deviation For Each Proposed Heuristics By Instance Category With Missing Operations

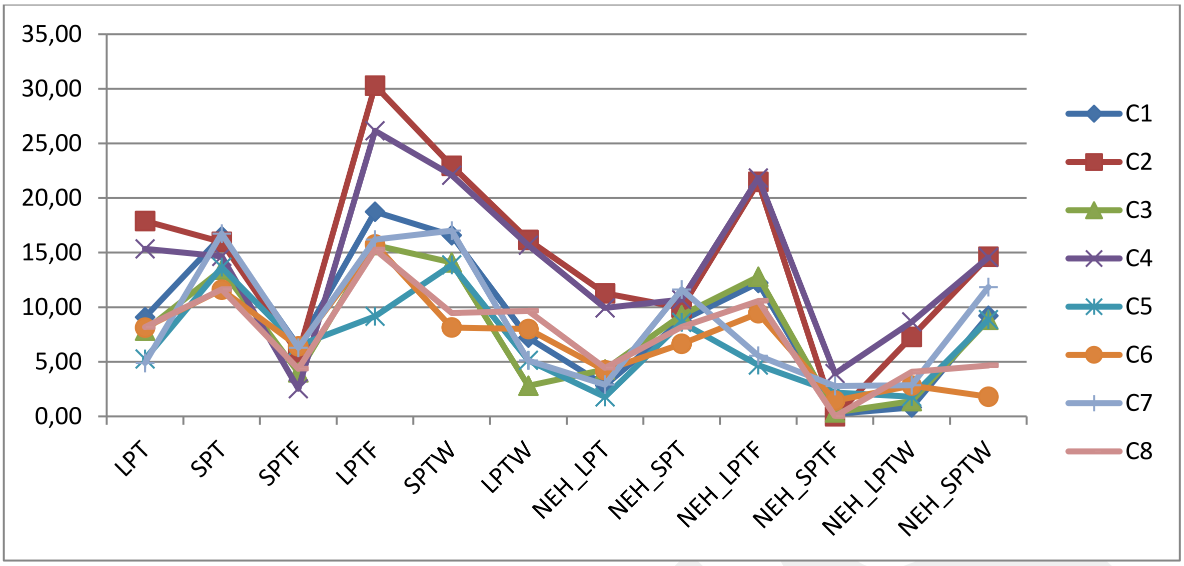

Figure 5. Comparison Of Average Percent Relative Deviation For Each Proposed Heuristics By Instance Category.

6. CONCLUSIONS

In this paper, a new variant for the hybrid flow shop scheduling considering missing operations, sequence-dependent setup times and transportation times is discussed. The objective of the proposed problem is minimizing the total complete time of the schedule (makespan). The six dispatching rules and six heuristics are used to solve the proposed HFS problem. Computational experiments are carried out to evaluate the performance of the proposed heuristics and dispatching rules. The effects of a number of different factors (number of jobs, number of stages, number of machines, missing operations level) impressing the constructing of the solutions of the problem are analysed. The comparative results depicted that NEH heuristic based on SPTF showed the best performance for the proposed HFS problems.

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