Solving "Resource Constrained Project Scheduling Problem" (RCPSP) with Bench Marked Hybrid Algorithm's

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Abstract:

In the paper, we give illustrated reviews, new approaches and results of how rcps –problems are being solved with Hybrid algorithm's. Firstly, considering Hybrid Genetic Algorithm (HGA), Vicente [a] et al 2007, introducing many changes in Genetic algorithm (GA) paradigm, resulting in HGA giving fast and high quality algorithms out performing state-of-the-art-algorithm (SOTAA). for rcps-problem. Secondly, Lin [a] et al 2005 claims a Hybrid Meta-heuristic ANGEL for rcps-problem. ANGEL combines ant colony optimization (ACO), GA and Local search strategy. For ANGEL to proceed it firstly searches for solution space and generates activity lists for the initial population from ACO. With GA following execution and pheromone is updated in ACO. Proposing an efficient local search method when ACO and GA reaching optimum solutions. Thirdly, Sonda Elloumi [a] et al 2009 implementing multi-mode rcps-problem with Hybrid rank based evolutionary algorithm (EA) , proposing i)transforming single objective multi-mode rcps-problem to bi-objective to cope with potential violation to non-renewable resource constraints and relaxing latter constraints, ii) fitness function on an adaptive relying clustering method. Lastly, Ling Wang et al 2012 presents Hybrid estimation distribution algorithm (HEDA), here individuals encode based on extended activity list (EAL) and then decoding with serial generation scheme (SGS).

KEY WORDS: rcps-problem, ACO, EAL, HGA, HEDA, ANGEL, EAL, SGS, EA.

1. Introduction:

Rcps-problem has been studied over and over since the last few decades hoping to achieve results to all rcps-problems available, Herroelene et al 1998, Brucker et al 1999, Kolisch and Padman 2001 and many more. From job-shop generalization we have learnt that rcps-problem is NP- hard in the strong sense Blazewicz et al 1983.Heuristic procedures remain feasible for handling practical rcps-problems. Valls et al 2005 shows double justifications (DJ) as a simple method incorporating many diverse rcps-problem algorithms producing improved quality schedules without consuming extra computational time. This DJ method also known as forward and backward scheduling to developing multi-pass heuristic scheduling procedures example Li and Willis 1992, Ozadamar and Ulusoy 1996. Currently many meta-heuristics methods are being proposed. Kolisch gave an extensive detail on parallel and serial scheduling schemes. Under two scheduling schemes six priority rules were tested. Herroelen et al surveyed various branch and bound algorithms for rcps-problem. Kolisch and Padman provided exact and heuristic methods to class scheduling problems for projects. Brucker et al provided classification scheme to relationship between rcps-problem and machine scheduling. Demeulemeester and Herroelen showed depth first branching scheme having dominance criteria and bounding rules.

Meta-heuristics are also proposed including GA, simulated annealing, tabu search, ant colony optimization, path relinking, and Hybrid algorithms (HA), HA which we will be focusing on in this paper. In the latest experiments, meta-heuristics have outperformed heuristic methods.

Sonda. E et al presents another part to rcps-problems adding multi-modes. This has much closer relation to real problem as rcps-problem deal with each activity performing in one out of several modes and dealing with more than one resources. Clearly, multi-mode rcps-problem is complex than rcps-problem, proved Sprecher and Drexl et al 1998 that "highly constrained project with at least 20 activities and 3 modes per activity cannot be solved by exact optimization procedure within a reasonable time". Kolisch and Drexl et al 1997 demonstrated that at least two non-renewable resources are taken then the problem of getting a feasible solution to multi-mode rcps-problem is NP-complete. Drexl and Grunewald 1993 proposed stochastic scheduling, Slowinski et al 1994 makes decisions support system for multi-objective multi-mode rcps-problem based on three heuristics, parallel priority rule, simulated annealing and branch and bound.

Meta-heuristic studies have also devoted in procedures to solving multi-mode rcps-problem. Damak et al 2009 solves his problem applying differential evolution algorithm, Jarboui et al 2008 applying particle swarm algorithm just a few to name.

Till date many priority rules have been proposed, 1) greatest rank positional weight rule, most total successors rule, shortest processing time rule Alvarez Valdes and Tamarit et al 1989, minimum slack rule, latest start time rule, Davis and Patterson et al 1975, latest start time rule kolisch 1995,, worst case slack rule Kolisch 1996a, resource scheduling method rule Shaffer, Ritter and Meyer et al 1996. With the technologies these days meta-heuristics (GA, simulated annealing (SA), tabu search (TS), particle swarm optimization (PSO), scatter search (ss)) are all part of solving rcps-problem.

In this paper the following is said in part 2) problem descriptions of different hybrid algorithms applied to rcps-problem, the rest of the paper has results and explanations followed by in section 3 a brief summary of Hybrid algorithms

2. The problem described

Referring from [1] we observe that Valls et al. uses the approach of HGA with the new elements of peak crossover operators, where the main objectives are to exploit knowledge of the problem and to identify and mix together good parts of the solution who have really contributed to quality. Opposite to the normal behavior of randomly selecting good parts without any guarantee or even indication of their quality. Valls et al.

HGA has 2 phases to solving it i) initially general searching ii) searching in neighborhood for best solutions. To ease comparison between state of the art rcps-problem heuristics, HGA generates maximum of nsche schedules. HGA the individuals are the activities list representations of the schedule. Valls et al uses the standard sets of j30, j60, and j90 and j120 respectively from Kolisch et al 1995 ProGen. The test sets considered by Valls et al were 30, 60, 90 and 120 set for each activity with limiting his number of generated schedules to maximum 5000.

HGA gathers best results for all its parameter values but one that s RF= 0.25 and that HGA π= 1, 1-phase it improves DJGA for all other parameter values but RS= 0.3, 0.4 [1].

Number of better and worse schedules by RS values in j120

	HGA($\pi = 1$,1phase) versus DJGA		HGA versus DJGA	
	N_better_sched	N_worse_sched	N_better_sched	N_worse_sched
RS = 0.1	72	25	88	13
RS = 0.2	49	32	56	19
RS = 0.3	26	28	31	19
RS = 0.4	10	19	20	10
RS = 0.5	4	3	10	3
Total	161	107	205	64

Table 1: HGA verses DJGA [1].

Valls et al. globally proves true for RS =0.1, 0.2, 0.5 but not for RS= 0.3 and 0.4. Seemingly that peak crossover operators are more progressive when dealing with tough instances then the typical easy once [1].

Valls et al compares this results with state of the art heuristic algorithm the results only indicated that HGA was capable of providing optimal solutions for very small computations.

Average deviations from optimal makespan in j30

Author(s)	Algorithm type	Max_N_sched		
		1000	5000	50,000
Kochetov and Stolyar (2003)	GA, TS, path reli.	0.10	0.04	0.00
Valls et al.	Hybrid GA	0.27	0.06	0.02
Alcaraz and Maroto (2001)	GA	0.33	0.12	–
Valls et al. (2005)	DJGA	0.34	0.20	0.02
Tormos and Lova (2003a)	Sampling + BF/FB	0.25	0.13	0.05
Nonobe and Ibaraki (2002)	Tabu Search	0.46	0.16	0.05

Table 2: [1] considering the top ranked make span for j30

To conclude we have seen the attempts of Valls et al prove HGA out performing state of the art algorithm for rcps-problem for instances of j60 and j120 and it is very competitive with j30.

Problems: problems that we saw faced by Valls et al for his HGA were firstly as the generations number increased, it became more difficult for obtaining global improvements, secondly new information's were available throughout his search where creating new populations for evolutionary process could have been applied and GA therefore could guide to have promising or new areas for search space.

CP_dev values in j60

Author(s)	Algorithm type	Max_N_sched		
		1000	5000	50,000
Valls et al.	Hybrid GA	11.56	11.10	10.73
Kochetov and Stolyar (2003)	GA, TS, path reli.	11.71	11.17	10.74
Valls et al. (2005)	DJGA	12.21	11.27	10.74
Hartmann (2002)	Self-adapting GA	12.21	11.70	11.21
Hartmann (1998)	Activity list GA	12.68	11.89	11.23
Tormos and Lova (2003a)	Sampling + BF/FB	11.88	11.62	11.36
Tormos and Lova (2003b)	Sampling + BF	12.14	11.82	11.47
Alcaraz and Maroto (2001)	GA	12.57	11.86	–
Tormos and Lova (2001)	Sampling + BF	12.18	11.87	11.54
Bouleimen and Lecocq (2003)	SA	12.75	11.90	–

Table 3: HGA performs 3rd best in j60 [1]

Hybrid genetic algorithm, Valls et al for rcps-problem it differs from a basic GA, for three reasons. Firstly peak cross over operators are used for HGA which are not purely randomly picked neither it's a contact free operator. Secondly, HGA uses double justifications systematically for simple, fast and powerful mechanisms for improving schedules. Lastly, HGA integrates 2- phase strategy which, re-starts the evolution from its neighbor's populations for the optimum schedule found in the first instance.

Now we move to Lin et al with is objective of rcps-problem to minimize the make span of a project using meta-heuristics also implementing a new hybrid algorithm. He states a special case of serial SGS (Schedule generation scheme), where Lin et al applies to produce a schedule also considering backward[1] and forward[2] schedules.

Lin et al applies ANGEL meta-heuristic for rcps-problem, where assuming precedence feasible activity list, procedure begins with ANGEL following a repetition of i) ACO (Ant colony optimization) with local search ii)GA is applied with local search and lastly a fine tuning search was conducted.

Lin et al designs ANGEL as a scheme for information exchange which enabled cooperation with ACO and GA. The population being ants in ACO employed a pheromone set which produces initial populations for GA [2]. GA in Lin et al obtains superior resulting solutions ever found for the global update rule was then applied to pheromone set. [2]

Lin et al as Valls et al also apply the same sets from kolisch and Sprecher et al with ProGen for sets j30, j60, having instances of 480 and j120 having instances of 600. Therefore, Lin et al

[1] A backward schedule – is a mapping set of operations where the start time are set as the latest possible and satisfying resource constraint [2]

[2] A forward schedule- is a mapping set of operations where the start time are set as the earliest possible and satisfying resource constraint [2]

found that solutions qualities with local search were only 2% greater than for j60 and j120 and stated that it was helpful. ANGEL’S population size is much smaller as was limited with 5000 schedules [2] and the evaluating small population are more alternative for ACO and GA were performed, with ACO and GA having better interactions with better performances. [2]

Performance of the local search procedure in ANGEL

Instance set	J30	J60	J120
Number of local search executed	73,322	305,861	728,836
Ratio of local search that achieves improvement (%)	38.89	45.21	67.11
Average rate of makespan improvement achieved by each improved local search (%)	4.36	3.67	2.95

Table 4 performance of local search with ANGEL [2]

Problem: Also Lin et al compares pair wise comparisons to detect differences both ANGEL, ANGEL-1 and ANGEL-2[2] tested by Wilcoxon signed test rank, proved that a significant difference in the level solving j30 because they were not difficult to solve. ANGEL in Lin et al showed better performances than ANGEL-1 for j60 and ANGEL-2 for j120. [2] Lin et al stated possible reasons being LFT Heuristics are not too inferior with ACO. [2]

Solving rcps-problem for Lin et al with his Hybrid meta-heuristic called ANGEL combined with ACO, Local search and GA, ANGEL was the third best for j30.j60 and 5th to j120 in the comparing list against 1000 and 5000 schedules[2] Lin et al proves that his study is very effective for improving quality solutions.

ANGEL configuration	Population size	Final search schedules	Average deviation (%)	Average CPU time (seconds)
(a) J30				
ANGEL with local search	30	2000	0.08	0.11
ANGEL-1 with local search	20	0	0.09	0.11
ANGEL-2 with local search	20	2000	0.11	0.12
(b) J60				
ANGEL with local search	20	2000	11.27	0.76
ANGEL-2 with local search	20	2000	11.40*	0.86
ANGEL-1 with local search	20	0	11.47*	0.87
(c) J120				
ANGEL with local search	20	2000	34.49	4.79
ANGEL-2 with local search	20	2000	34.57	4.58
ANGEL-1 with local search	20	0	35.16*	5.55

Table 5: shows the top 3 avg. dev. From optimum or critical lower bound for ANGEL configurations, pop. Size and no. of schedules evaluated in the final search algorithm. [2]

Elloumi et al proposed evolutionary algorithm (EA) for solving multi-mode rcps-problem. EA deals with both sequencing and mode assignments problems. Multi-mode rcps-problem in history has 2 basic comparison i) CPU time and the number of generated schedules [3]. Elloumi et al compares the variants in the best leading configurations with the set of instances 5000 schedules Alcaraz et al 2003 and Jozefowska et al 2001. EA compared with GA of Alcaraz et al, Hartmann et al and Ozdamar et al and the local search based algorithm by Kolisch and Drexl 1997 for 6000 computed schedules stopping criterion [3]

Elloumi et al proves EA out performs Alcaraz et al's GA with the new fitness functions and operator variants. Elloumi et al states that Kolisch and Drexl's 1997 local search gives better results than Ozadamar et al and it does not outperform EA. Simulated annealing (SA) by Jozefowska et al has 3 times worse average deviation results than EA.

Problems: Brunch and bound algorithm given by Sprecher and Drexl et al out performs EA's j10 and j12 instances as it provides entirely optimum solutions, whereas for bigger size of the problems. [3]

Elloumi et al proposed new Hybrid algorithm EA, for solving average deviation *allowed nonrenewable resources as average deviation have NP-completeness thus violation has penalty value issued to the solutions.[3] this penalty was dealt with a criterion which was minimized thus its algorithm solved becoming a bi-objective. Having to introduce cluster algorithm to computer densities they [3] enforced neighbor solutions should belong to same cluster and then assigned to same density. Elloumi et al's proposal came down to becoming an adaptive grid for the solution set.*

Comparison with HGA and SDBB. EA with *K*-means based fitness function stopped at number of different ranks. 1 s stopping criterion. J10-20 and J30. (Deviations are computed from makespan lower bounds for J30.)

J	Av. dev.			Max. dev.			Feasible			Optimal		
	Our EA	HGA	SDBB	Our EA	HGA	SDBB	Our EA	HGA	SDBB	Our EA	HGA	SDBB
10	0.09	0.06	**0.00**	13.04	6.3	0.0	100.0	100.0	100.0	98.6	98.7	100.0
12	0.13	0.14	**0.12**	**8.69**	9.1	17.9	100.0	100.0	100.0	97.3	97.3	**98.2**
14	**0.43**	0.44	1.46	12.13	**10.3**	33.3	100.0	100.0	99.6	**90.0**	89.8	85.7
16	**0.46**	0.59	3.81	13.79	**10.5**	52.4	100.0	100.0	99.5	**88.9**	87.8	69.5
18	**0.67**	0.99	7.48	**13.24**	13.3	77.4	100.0	100.0	98.0	**84.1**	78.3	57.4
20	**0.91**	1.21	11.51	21.53	**14.2**	78.6	100.0	100.0	96.4	**78.52**	73.3	47.3
30	**2.04**	16.93	57.22	**14.55**	151.9	244.0	86.17	86.3	55.8	–	–	–

Table 6 [3] comparison on HGA and SDBB against EA

Comparison with JPS and DDE.; simple-rank-based EA with *POP* = 120; *K*-means based EA with *POP* = 60; 0.15 s/activity stopping criterion.

J	Av. dev.				**Optimal**			
	Simple rank EA	*K*-means EA	JPS	DDE	Simple rank EA	*K*-means EA	JPS	DDE
10	**0.03**	0.09	0.03	0.09	**99.25**	97.95	99.25	99.3
12	**0.05**	0.12	0.09	0.11	**98.72**	97.44	98.47	99.3
14	**0.26**	0.3	0.36	0.34	**93.93**	92.56	91.11	97.6
16	**0.25**	0.45	0.44	0.42	**93.09**	89.45	85.91	96.38
18	**0.45**	0.7	0.89	0.59	**88.22**	84.06	79.89	94.43
20	**0.58**	0.91	1.10	0.7	**84.81**	77.76	74.19	91.75

Table 7 [3] seeing JPS and DDE against EA.

Estimation of distribution algorithm (EDA) by Wang et al is one of the emerging general framework set of probability distribution based optimization algorithm, Larranaga and Lozano et al 2002. EDA tries to predict movements of population in searching space and estimates underlying probability distribution for the encoded variables of elite individuals. [4] Wang et al's EDA does not directly work on a schedule but on representations of the schedule.

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Wang et al proposed an extended activity list (EAL), which contains 3 sections, an activity list, a finish list and a start list. After Wang et al generated the new EAL, he implemented it to be used against SGS to evaluate EAL. [4]

Wang et al's Hybrid EDA firstly has a probability matrix which is initially uniform and implementing it on j30, j60 and j120 instances.[4] The average time of CPU consumed by HEDA is acceptable and increases linearly with respect to number of schedules of every problem.[4] The deviation value decreases as the maximum number of schedules increases making HEDA a very robust.[4]

HEDA proves for set on j30 7th best for both 1000 and 500 schedules instances among 16 algorithms [4]. For j60 set HEDA is the top 8th for 1000 instances and 7th for 5000 instances for the total 16 other algorithms. For set j120, HEDA becomes the 7th best for 1000 instances and 4th for 5000 instances. HEDA is extremely competitive with all existing algorithms for solving rcps-problem especially for media and large scale problems [4]

HEDA proposed by Wang et al for estimation distribution as a hybrid algorithm to solving rcps-problem adopted statistic tool for predicting most promising areas. HEDA being most promising when using extended activity list (EAL) and HEDA decoding for improving serial SGS.

Problem set	Schedules	Ave.LB.Dev (%)	Min.LB.Dev (%)	Max.LB.Dev (%)	Var.	Ave.CPU (s)	Min.CPU (s)	Max.CPU (s)
J30	1,000	0.38	0.33	0.41	5.32e-08	0.0159	0.0158	0.0160
	5,000	0.14	0.11	0.17	2.92e-08	0.0796	0.0794	0.0797
J60	1,000	11.97	11.18	12.54	6.51e-05	0.0919	0.0905	0.0935
	5,000	11.43	10.85	11.99	4.99e-05	0.4074	0.4054	0.4108
J120	1,000	35.44	33.86	36.73	1.15e-04	0.6220	0.6167	0.6304
	5,000	33.61	32.87	23.74	9.54e-05	2.8426	2.8273	2.8792

Table 8 results of HEDA [4]

3. Conclusion

We have proved in this paper that no matter what the problem is a solutions is what we are looking for in rcps-problems. Many have stated from classical, traditional, heuristic, GA, adaptive and now Hybrid algorithms to get solutions to the toughest of problems in rcps-problems with the optimum results. We have justified with the more research we do the more achievements are made. Now getting proofs for these Hybrid algorithms which have either proved very successful to moderately successful not failing. The Hybrid algorithm's that Wang et al, Elloumi et al, Lin et al and Valls et al have for the same instance and schedules set j30, j60, j90 and also j120 used as the pervious scholars did and still achieved stunning new results. We therefore, in our future work will present an advanced selection of rcps-problem.

4. Reference

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