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A firefly algorithm for the alternative subgraphs assembly line balancing problem

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Abstract

In the developing industrial world, assembly lines play an important role in the production of larger quantities of products and efficient use of scarce resources. Assembly line consist an equipment system for flow of workpieces in mass-production operations. Today, the production of many products, especially multi-part products, is carried out with the help of these assembly line systems. But we encounter with real life problems of the manufacturing products in these complex systems. Assembly line balancing problems are one of them. Assembly line balancing problems (ALBP) simply assign a set of tasks to a group of the workstations by considering precedence relations between the assembly tasks. Precedence relations are represented by a predetermined graph. But the assembly process may have subgraphs of alternative priorities. This has led to the emergence of the Alternative Subgraph Assembly Line Balancing Problems (ASALBP). Such problems are caused by changing the processing times of the jobs depending on the order of operations with different mounting alternatives. This study will focus on proposed the new metaheuristic firefly for the solution the Alternative Subgraph Assembly Line Balancing Problem

1 Introduction

Assembly lines are flow-line production systems which are of a combination of workstations with a material handling system. The assembly line balancing problem is one of the main topics in the literature on optimization of the assembly lines. In this context, assembly line balancing problem (ALBP) is known as the decision problem of optimally balancing the assembly work among the workstations with respect to some objectives (Scholl, 1999).

There are many studies on assembly line balancing problems in the literature, Salveson (1955) developed first mathematical formalization of the assembly line balancing (ALB) problem.

On the other hand, an early one of the best known classification was prepared by Baybars (1986) on assembly line balancing problems. In this study, assembly line balancing problems are divided into two groups: the Simple Assembly Line Balancing Problem (SALBP) and the General Assembly Line Balancing Problem (GALBP).The simple case (SALBP) that is an assembly line where only one standard product is produced on a serial assembly line. The problems with greater complexity and constraints are considered to be GALBP.

In ALBP studies, priority relations are simpler, while in real life problems priority relations have a more complex structure. Therefore, it is considered that ALBP should be discussed in more detail and a new GALBP named ASALBP (Alternative Subgraph Assembly Line Balancing Problem) was developed by Capacho and Pastor. This problem is mostly related to the assembly line balancing problem faced by suppliers with a large product range and product number, which enables them to offer more options to their customers in direct proportion to increasing customer needs. The distinctive aspect of the alternative sub-graph assembly line balancing problem is that it has alternative sub-graph priority relationships, not definite priority relationships. In the alternative subgraph assembly line balancing problem, mounting alternatives for different parts of an assembly or manufacturing process are considered. Each process is represented by a sub-graph that specifies the tasks and task priority relationships required to process a particular product. With the increase in the number of alternatives and the expansion of the solution space, the problem is evaluated in the NP-hard problem class.

The problem has two basic different solution methods. The first one is the exact solution methods and the other one is approximate solution methods. Capocho and Pastor (2005) presented the integer linear mathematical model to solve of the problem. Capocho and Pastor, Dolgui and Guschinskaya (2006) studied to solve the alternative subgraph assembly line balancing problems by way of heuristic methods. Capacho and Pastor (2014) were used to solve the Alternative Subgraphs Assembly Line Balancing Problem (ASALBP) with metaheuristic approach (Greedy Randomized Adaptive Search Procedure) GRASP in this article. The firefly algorithm is a new metaheuristic algorithm recently developed by Yang. Firstly, although it is suitable for the solution of continuous problems, it has been applied within the discrete problems in the literature and good results have been obtained.
Sayadia *et al*. presented a discrete firefly algorithm to minimize cycle time for flow shop scheduling problems. Marichelvam *et al*. presented a discrete firefly algorithm for the multi-objective hybrid flow shop scheduling problems. A discrete firefly algorithm was proposed by Jati and Suyanto to solve the travelling salesman problem. Osaba *et al*. proposed a discrete firefly algorithm to solve a rich vehicle routing problem modelling a newspaper distribution system with recycling policy. When the literature is examined, it is suggested that the big problems will be solved by metaheuristic methods. In this study, we aimed to minimize the number of machines in ASALBP by using firefly algorithm. The rest of the work will continue as follows: Section 2 ASALBP definition is explained in detail. Section 3 Firefly algorithm and its application were given to the ASALBP. Section 4 presents computational experiments. Section 5 provides computational conclusions and analysis. Section 6 explains of conclusion.

2 Alternative subgraph assembly line balancing problem's description

The alternative sub-graph assembly line balancing problem is that the product has different installation alternatives during the assembly process. The alternative sub-graph assembly line balancing problem consists of two sub-problems. The first is the decision problem and one of the installation alternatives needs to be selected. The second is the line balancing problem and it is intended to assign tasks to the workstation in a minimum number. The problem may come from multiple assembly sections and these assembly sections may have different sub-graphics. Task priorities may change in sub-graphs, and this change may result in different task times. All these changes cause a change in the objective function. One small problem for example,

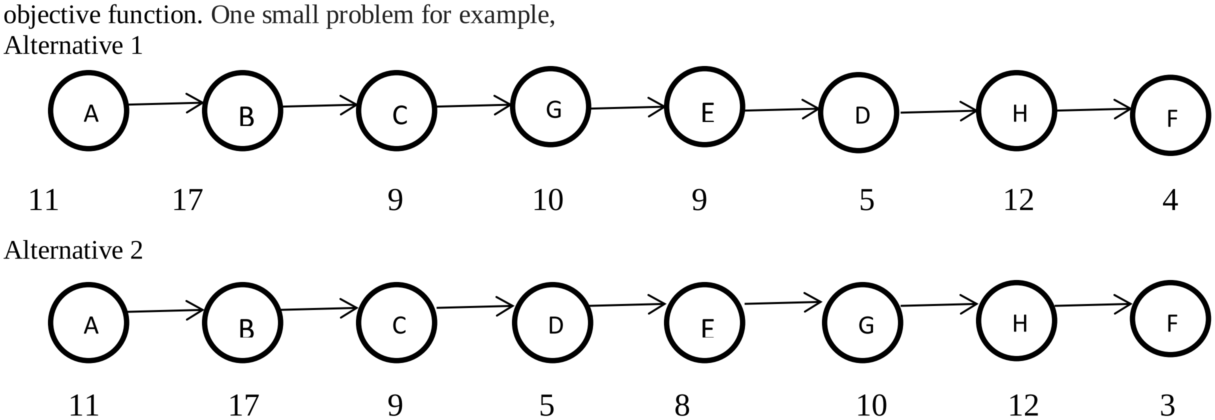

Figure 1 Two assembly alternatives

As in Figure 1, the task sequences and times for each subassembly may change, which may cause the number of stations to change in the objective function.

3 Firefly algorithm

The firefly algorithm is a nature-inspired algorithm, based on the principle that fireflies produce light with special structures in their bodies in order to catch their prey or draw their pairs. First of all, it is suggested for continuous problems, but it is tried to be adapted to discrete problems due to its success in problem solving. The creation of the firefly algorithm is based on the following three main ideas: 1) All fireflies are of the same sex, in which case all individuals are affected in the same way.2) It is the intensity of light they emit that makes them influenced by each other.

Whichever emits more light and closer to the distance in the range, the other moves towards it. Fireflies move randomly if they have equal light intensity.3) the objective function is proportional to brightness. In the firefly algorithm there are three steps:

Attractiveness: $\beta(r) = \beta_0 e^{-\Upsilon r^m}$, (m>=1)
r is the distance between two fireflies, β_0 is the attractiveness at r=0 and Υ is a fixed light absorption coefficient.

Distance: $r_{ij} = \|X_i - X_j\| = \sqrt{\sum_{k=1}^{d} (X_{ik} - X_{jk})}$
The distance between any two fireflies i and j at X_i and X_j expressed by the Cartesian distance, k is parameter of firefly, d is parameter number.

Movement: $X_i = X_i + \beta_0 e^{-\Upsilon r_{ij}^2} (X_j - X_i) + \alpha\ (\mathrm{rand} - \frac{1}{2})$
i. firefly is affected by the brighter j firefly and j moves towards the firefly. Υ, α, rand ; These are the parameters used for continuous problems, taken within a certain value range.

4 Implementation of Firefly Algorithm to ASALBP

The swarm-based firefly algorithm developed by Xin -She Yang (2008) was examined in previous discrete studies and adapted for ASALBP. 1) Randomly Subgraph Selection: An alternative subgraph was selected for each subassembly and tasks were chosen to form the solution.
2) Initial population: A starting solution population was created by paying attention to the constraints by the rank positional weight method.
3) Distance: Then the distance step of the firefly algorithm was applied on the initial solutions. The objective function of each solution has been compared with each other and the solution function has been tried to improve (the minimization of the number of stations is aimed in our problem). The number of different tasks in each solution as the distance is found by the Hamming distance formula.
4) Movement: A random number between 2 and distance (r_{ij}) is selected and a neighbor search algorithm (swap) is applied to the poor solution to obtain a new solution under constraints.
n=Random (2, r_{ij}) n, the sequence of tasks that can be changed for each solution, paying attention to constraints.
X_i=Movement Function (X_i, n), every i. a new solution for firefly with tasks modified in accordance with constraints. So, each firefly moves n times and each firefly will have n new solutions. After all candidate fireflies move and come up population size × n new solutions, later n of the best fireflies will be selected for the new population. Then, best fireflies will be chosen basis of the objective function for the next iteration. This algorithm continues until the number of iterations is reached.

5 Computational experiments

The proposed algorithm was run to see the results of the computational experiments. A firefly algorithm for the alternative subgraph assembly line balancing problem was coded in MATLAB R2013 and run on a PC with Intel Core İ3 2.27 GHz CPU, 4GB RAM, running Windows 7.
Test instances
For the experiments, the data sets were used of Capacho and Pastor (2006) available at web site www.assembly line balancing.de. The data included 90 medium-sized problems and 45 large-scale problems. The data consisted of different sub-graphs, tasks and work completion times. The data structure is detailed in the related table.

Table 1 Data sets

Problem Cycle times						Number of subgraphs		
						5	8	11
						Number of tasks		
Gunther	41	49	49	61	81	37	37	37
Hahn	2004	2338	2806	3504	4676	56	56	63
Warnecke	54	62	74	92	111	63	63	67
Tonge	160	176	207	251	320	73	75	75
Lutz3	75	83	97	118	150	93	98	101
Kilbrid	51	79	92	138	184	45	46	48
Arc2	5785	6540	7916	9400	11570	115	121	125
Bartholdi	403	470	564	705	805	151	157	160
Scholl	75	83	97	118	150	299	302	305

6 Computational results and analysis

The results for the large and small problems are shown in tables 2 and 3. The results are calculated on the basis of which percentage of the best run problems are encountered. In Table 2, 39 optimal results were achieved in 90 problems for medium-scale problems, while 17 of 45 problems in Table 3 yielded optimal results. As a percentage, the best results were achieved in 43% of the medium-scale problems and the best results in 37% of the large-scale problems. In terms of solution time, the medium-scale problems can be solved in not too long periods, whereas in the large-scale problems, three big problems have not been achieved. Although the results provide better time results than previously developed integer programming, it is seen that the firefly algorithm should be developed in comparison with the heuristic studies made by Capacho et al (2006). However, in the study conducted with heuristic methods, 10 different heuristic methods were tried to obtain the results. The aim of this study is to achieve better results with a single meta-heuristic algorithm.

Table 2 Medium Scale Problem's Results Obtained by the Firefly Algorithm

Problem	n	Time	Sub assembly number	Subgraph number	Firefly solution	Optimal	Solving Time (seconds)
Gunther	37	41	1	5	14	14	2
	37	44	1	5	14	12	2
	37	49	1	5	11	11	2
	37	61	1	5	9	9	2
	37	81	1	5	7	7	2
	37	41	2	8	14	14	8
	37	44	2	8	16	12	8
	37	49	2	8	13	11	9
	37	61	2	8	10	9	9
	37	81	2	8	8	7	9
	37	41	3	11	17	14	32
	37	44	3	11	16	12	31
	37	49	3	11	14	11	31
	37	61	3	11	11	9	31

	37	81	3	11	8	7	30
Hahn	56	2004	1	5	8	8	17
	56	2338	1	5	7	7	16
	56	2806	1	5	6	6	16
	56	3507	1	5	5	5	19
	56	4676	1	5	4	4	17
	56	2004	2	8	8	8	50
	56	2338	2	8	7	7	51
	56	2806	2	8	6	6	53
	56	3507	2	8	5	5	53
	56	4676	2	8	4	4	51
	63	2004	3	11	8	8	296
	63	2338	3	11	7	7	297
	63	2806	3	11	6	6	306
	63	3507	3	11	5	5	291
	63	4676	3	11	4	4	298
Warnecke	63	54	1	5	33	31	18
	63	62	1	5	29	27	17
	63	74	1	5	23	22	18
	63	92	1	5	18	17	18
	63	111	1	5	15	14	18
	63	54	2	8	33	31	71
	63	62	2	8	29	27	66
	63	74	2	8	23	22	65
	63	92	2	8	18	17	65
	63	111	2	8	15	14	65
	67	54	3	11	33	31	233
	67	62	3	11	29	27	249
	67	74	3	11	23	22	227
	67	92	3	11	18	17	234
	67	111	3	11	15	14	241
Tonge	73	160	1	5	23	23	27
	73	176	1	5	22	21	27
	73	207	1	5	18	18	28
	73	251	1	5	15	14	28
	73	320	1	5	12	11	29
	75	160	2	8	23	23	88
	75	176	2	8	22	21	86
	75	207	2	8	18	18	88
	75	251	2	8	15	14	89
	75	320	2	8	12	11	88
	75	160	3	11	23	23	402

	75	176	3	11	22	21	408
	75	207	3	11	18	18	410
	75	251	3	11	15	14	408
	75	320	3	11	12	11	416
lutz3	93	75	1	5	24	23	89
	93	83	1	5	21	21	90
	93	97	1	5	19	18	90
	93	118	1	5	15	14	91
	93	150	1	5	12	12	89
	98	75	2	8	24	23	402
	98	83	2	8	21	21	410
	98	97	2	8	19	18	406
	98	118	2	8	15	14	406
	98	150	2	8	12	12	407
	101	75	3	11	24	23	1432
	101	83	3	11	21	21	261
	101	97	3	11	19	18	1465
	101	118	3	11	15	14	340
	101	150	3	11	12	12	329
Kilbrid	45	57	1	5	10	10	17
	45	79	1	5	8	7	7
	45	92	1	5	7	6	7
	45	138	1	5	5	4	7
	45	184	1	5	4	3	7
	46	57	2	8	10	10	22
	46	79	2	8	10	7	23
	46	92	2	8	8	6	23
	46	138	2	8	4	4	22
	46	184	2	8	3	3	22
	48	57	3	11	10	10	83
	48	79	3	11	8	7	82
	48	92	3	11	7	6	83
	48	138	3	11	4	4	81
	48	184	3	11	3	3	82

Table 3 Big Scale Problem's Results Obtained by the Firefly Algorithm

Problem	n	Time	Sub assembly number	Sub graph number	Firefly Solution	Optimal	Solving Time
ARC2	115	5785	1	5	27	27	89
	115	6540	1	5	24	24	92
	115	7916	1	5	20	20	87
	115	9400	1	5	17	17	87

	115	11570	1	5	14	13	88
	121	5785	2	8	27	27	412
	121	6540	2	8	24	24	410
	121	7916	2	8	20	20	405
	121	9400	2	8	17	17	424
	121	11570	2	8	14	13	407
	125	5785	3	11	27	27	311
	125	6540	3	11	24	24	315
	125	7916	3	11	20	20	314
	125	9400	3	11	17	17	314
	125	11570	3	11	14	13	311
Bartholdi	151	403	1	5	15	14	73
	151	470	1	5	13	12	70
	151	564	1	5	11	10	75
	151	705	1	5	9	8	75
	151	805	1	5	8	7	75
	157	403	2	8	15	14	321
	157	470	2	8	13	12	320
	157	564	2	8	11	10	321
	157	705	2	8	8	8	334
	157	805	2	8	8	7	326
	160	403	3	11	15	14	1061
	160	470	3	11	12	12	1020
	160	564	3	11	11	10	1028
	160	705	3	11	8	8	1020
	160	805	3	11	8	7	1065
Scholl	299	1394	1	5	52	51	326
	299	1584	1	5	45	44	721
	299	1699	1	5	42	42	663
	299	2049	1	5	35	34	785
	299	2787	1	5	26	25	682
	302	1394	2	8	52	51	602
	302	1584	2	8	45	44	597
	302	1699	2	8	42	42	590
	302	2049	2	8	35	34	605
	302	2787	2	8	26	25	600
	305	1394	3	11	52	51	681
	305	1584	3	11	45	44	672
	305	1699	3	11	-	42	-
	305	2049	3	11	-	34	-
	305	2787	3	11	-	25	-

7 Conclusion

In this study, the metaheuristic approach Firefly algorithm was used to solve the Alternative Subgraph Assembly Line Balancing Problem. Firstly, the ranked positional weight method was used to generate an initial solution to insert it into the intial population and then the discrete firefly algorithm used to improve the intial population. The proposed algorithm tested on an existing benchmark set containing medium and large scale instances. The obtained results compared against the benchmark problems' optimal solutions taken from the related literature. As a result, while medium-sized problems are developed for time, they need to be improved for large problems.

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