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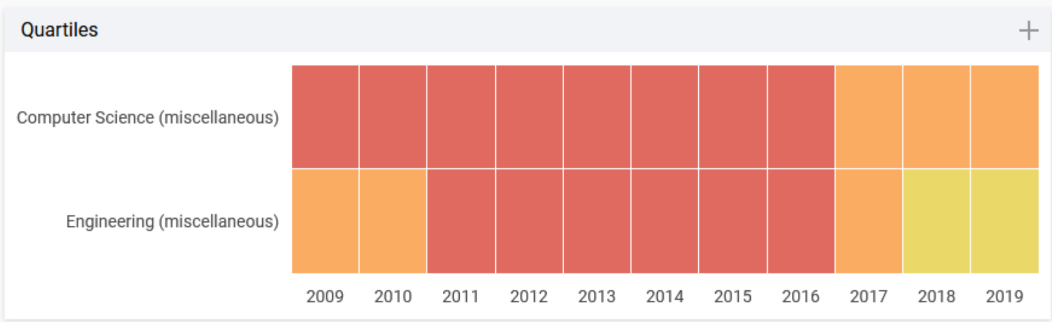

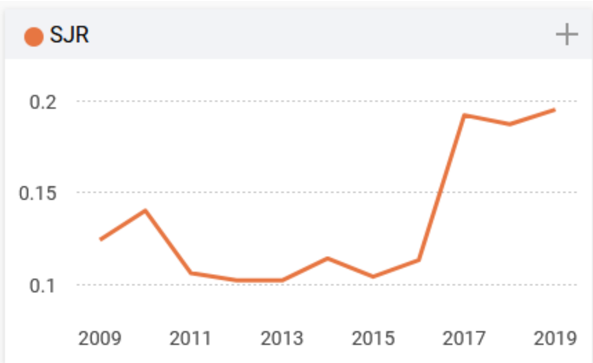

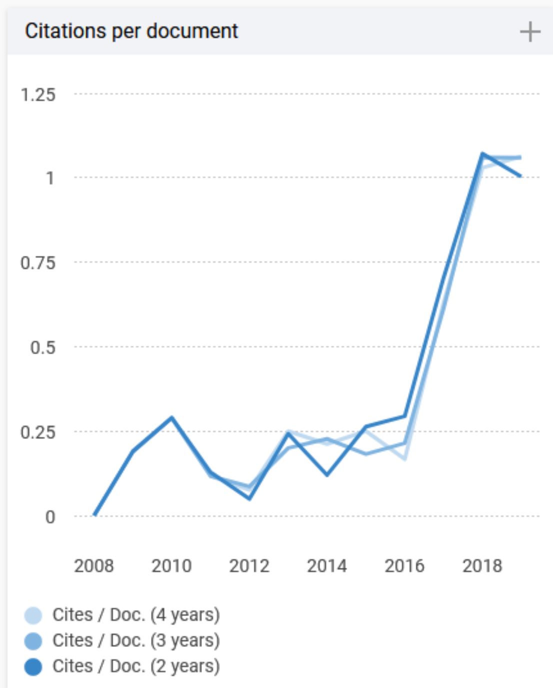

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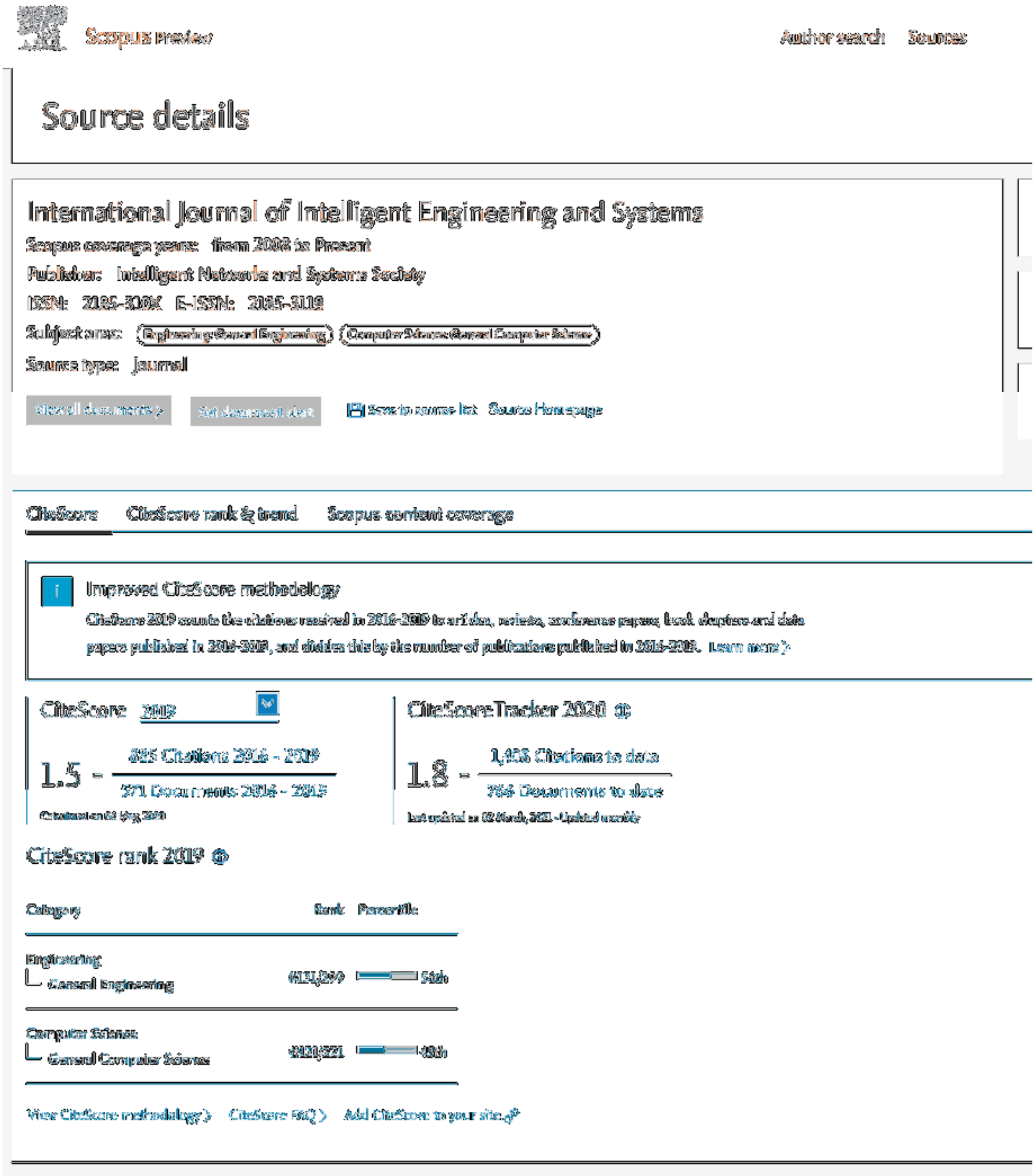

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- Vision computing
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- Grid computing

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Comparing Various Genetic Algorithm Approaches for Multiple-choice Multi-dimensional Knapsack Problem (mm-KP)

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Abstract: One of the essential and well-known classes of combinatorial optimization problems commonly studies by researchers in the last five decades is called the Knapsack Problem (KP). Many variants of KP have been introduced for different real-world applications. Among them, the multiple-choice multi-dimensional Knapsack Problem (mm-KP) is the most complex model with an NP-hard problem. Several authors have reported the robustness of heuristics for mm-KP; irrespective of its advantages, no method currently has the ability to solve the problem optimally all time. This paper aims to determine the best GA strategy and evaluate the performance of several heuristic algorithms to solve mm-KP. We investigate the use of two techniques that are included in the GA approach. The first, two different strategies are adopted to handle infeasible chromosomes, namely penalty and repairing procedure. Second, we develop a new-simple local search to improve the quality of the solution found. Experimental studies on the 13 (thirteen) Benchmark instances are conducted to evaluate the effectiveness of the approach based on solutions quality, the number of the optimal solution reached, and average errors. The results showed that hr-GA tends to reach optimal/near-optimal solutions. Furthermore, the results from studies on heuristic algorithms also show that hr-GA is a promising approach, with local search used to immensely improve the quality.

Keywords: Repairing strategy, Local search, Heuristic method, Genetic algorithm, Knapsack problem.

1. Introduction

In 1950, Dantzig introduced the classical Knapsack Problem (KP), which is one of the famous combinatorial optimization problems. It represents the problem of selecting the subsets of the *n* items to maximize the corresponding profit, and the total weight does not exceed the Knapsack capacity. Practical applications of KP can be found in some of our daily life, such as the everyday diet program, an optimal investment plan, cargo loading, cutting stock, budget control, and financial management [1]. Different variants of KP are found in the literature, including, multiple-choice KP (mc-KP), multi-dimensional KP (md-KP), and multiple-choices multi-dimensional KP (mm-KP) [2]. Among them, mm-KP is the most complex belongs to the class of an NP-hard problem. It is considered as a variant of the md-KP where items are divided into groups, and precisely one item per group must be selected. The applications of mm-KP can be found in many real-life applications, including Chip Multiprocessor Run-time Resource Management [3], Global Routing of Wiring in Circuits [4], and Service Level Agreement [5].

The methods proposed in the literature to solve mm-KP can be grouped into two classes: exact and heuristic methods. Since mm-KP is an NP-hard problem, its search space exponentially grows as the problem size increases. Therefore, many researchers pay more attention to develop heuristic methods to solve mm-KP. Although the heuristics do not guarantee the finding of an optimal solution, those have been reported useful in determining optimal/near-optimal solutions for many hard optimization problems, including mm-KP.

To our knowledge, the first heuristic algorithm to solve mm-KP was reported by Moser et al. [6]. The authors introduced a Lagrangian Relaxation algorithm that was repeatedly permuting to reduce the infeasibility of solutions. A heuristic algorithm based on aggressive resource usage was proposed by Khan et al. [7]. This heuristic algorithm performs better than Moser's Algorithm. Then, Hifi presented several approaches to solve mm-KP. First, Hifi et al. proposed a heuristic approach with a guided-local search that used the principle based on trying several diversified solutions obtained after penalizing the costs of the objective function with penalties parameters [8]. Hifi et al. also developed an algorithm based on a reactive local search to try a diversification search and to escape local optima [9]. The authors reported that their methods are able to outperform Moser's and Khan's algorithms.

Later, Cherfi and Hifi presented column generation methods hybridized with branch-and-bound [10]. They reported that the approaches could obtain better solutions than former approaches on the benchmark instances. An ant colony algorithm approach to solve mm-KP was given by Iqbal et al. [11]. A heuristic method called oscillation (OSC Algorithm) was introduced by Htiouech et al. [12]. The authors used the constraint normalization method to improve the quality of solutions. Xia et al. developed another similar approach to the OSC algorithm, called Stochastic Local Search (SLS) [13]. The algorithm adopted a simple additive weighting scheme to adjust the weight (multiplier) on dimensions.

In one latest paper, Htiouech and Alzaidi proposed a heuristic algorithm called AMMKP [14]. The authors presented the way to decompose the mm -KP into many smaller sub-problems, and each subproblem then solved by an agent. The results show that the approach is able to solve several benchmark instances in the literature effectively.

Since Holland introduced it in 1975 [15], the Genetic Algorithm (GA) has been a prevalent heuristic method. Previous studies have shown the robustness of GA for various hard optimization problems, including the logistic problem [16] [17], scheduling problem [18], vehicle routing problem [19], and so on. For some specific cases, however, it often tends to provide local optimum and takes more time to reach optimal solutions. Therefore, it is crucial to carry out studies on designing an effective and efficient GA approach.

The most essential and influential component associated with the implementation of GA is the method used to represent the chromosome. For many optimization problems, it is difficult to express the chromosome in a way capable of fulfilling the constraint functions. This is because the generated chromosome in the population is either feasible or infeasible. Two strategies are usually adopted to overcome the infeasible situation, namely repairing and penalty [20]. Another critical issue in the applications of GA is associated with the strategies used to quit the local-optimal solution. The most common approach is to develop and hybridize GA with a local search technique [21].

This paper aims to determine the best GA strategy to solve mm-KP. To improve the quality of the solution, we developed a new simple local search and hybridized it into the GA loop. The approaches adopt both repairing and penalty strategy, namely as repairing-based (sr-GA), hybrid repairing-based GA (hr-GA), and hybrid penalty-based GA (hp-GA). Furthermore, some comparisons with other heuristic methods are also made based on the solution quality, average error, and the number of instances solved optimally.

To evaluate the approaches, we conducted some numerical experiments on set Benchmark test problems taken from OR-Library. The 13 (thirteen) widely studied instances are used to measure the performances of the algorithms. The experimental results show that hr-GA has the merit of high effectiveness and can obtain competitive results with the other heuristics.

We organize this paper into five sections. The second outlines the mathematical formulation of mm-KP. The brief designs of the proposed algorithms, including the chromosome representation, genetic operation, and local search technique, are presented in the third section. The numerical experiments and the comparison of results to other methods are described in the fourth section. Finally, conclusions are drawn in the last part.

2. Mathematical model and algorithm

Let

i index of class
j index of item
k index of resource
R_k resource constraint $R = R_1, R_2, R_3, \dots, R_m$
r_{ij}^k the need for the k^{th} resource for the j^{th} item in the i^{th} class

mm-KP aims to fill one item from each class of Knapsack in order to satisfy the resource capacity constraints and maximize the total profit values. Formally the mathematical formulation of mm-KP can be written as follows:

$$\max\ Z = \sum_{i=1}^{n} \cdot \sum_{j=1}^{r_i} x_{ij} v_{ij} \qquad (1)$$

s.t.

$$\sum_{i=1}^{n} \cdot \sum_{j=1}^{r_i} r_{ij}^{k}\, x_{ij} \ \leq R_k, k\, \epsilon \{1 \ldots \ldots, m\} \qquad (2)$$

$$\sum_{j=1}^{r_i} x_{ij} \ = 1, i\, \epsilon \, \{1, \ldots \ldots n\} \qquad (3)$$

$$x_{ij}\, \epsilon \{0,1), i\epsilon\{1, \ldots \ldots n\}, j\epsilon\{1, \ldots \ldots r_i\} \qquad (4)$$

Here, the value of x_{ij} is either 1 or 0, which implies that item j in the i-th class is chosen, or not chosen. The v_{ij} represents the profit value of item j in the i-th class.

3. Design of the algorithms

3.1 Chromosome representation and evaluation

When implementing GA for a specific application, the first step is to determine a way to represent a possible solution to the problems. We have to generate some feasible chromosomes, which is as much as the desired population size. For this research, we represent chromosome by using a string, that its length is equal to the number of classes. For example, the dataset I01 comprises of five groups (i), five items (j), and five resources (k) in each class, with a resource constraint (R_k) of 25. The chromosome representation for this instance I01 can be illustrated in Fig. 1. The data for this instance (I01) is as follows:

In the above chromosome, the index represents the class, while the value item gene represents the item index j in each class i. From the chromosome, the selected items are 4, 5, 3, 2, and 4 in the 1st, 2nd, 3rd, 4th, and 5th class. The decoding mechanism is done by selecting one item for each category. The number of resource consumption (r_{ijk}) of each item is used to check for the resource constraint. Here, the total value of r_{ijk} cannot exceed the (R_k) amount of each class, as shown in Table 2.

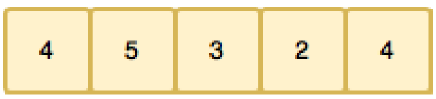

Figure. 1 Chromosome representation for instance I01

Table 1. Data for IO1 Instance

1					
7	1	3	1	1	6
17	1	4	9	9	3
25	4	3	9	8	2
35	4	5	8	0	6
36	6	8	3	0	7
2					
9	0	0	4	4	2
10	0	0	1	8	7
10	1	1	6	0	6
39	9	1	2	2	4
44	8	7	0	8	2
3					
15	2	0	5	5	5
19	2	3	2	6	2
20	3	1	6	4	7
44	6	7	5	6	9
50	9	5	9	2	2
4					
5	0	1	3	8	0
25	2	2	7	0	8
32	5	5	6	1	9
37	6	3	6	9	1
37	7	9	7	2	3
5					
24	4	0	7	0	2
30	4	8	9	0	0
32	5	2	7	2	0
43	5	5	9	5	2
44	9	2	2	2	3

Table 2. The decoding of the chromosome

	4	5	3	2	4
r_{ij1}	4	8	3	2	5
rij_2	5	7	1	2	5
r_{ij3}	8	0	6	7	9
r_{ij4}	0	8	4	0	5
r_{ij5}	6	2	7	8	1
R_k	23	25	21	19	25

3.2 Crossover and mutation

When implementing GA, two genetic operations are usually used to involve the new solution space, namely as crossover and mutation. The crossover operation is used to produce new offspring by recombining gen between selected parents. When choosing the crossover method, we have to consider the chromosome representation. There are several variants of the crossover methods introduced in the literature, such as one-point crossover, two-point crossover, PMX, WMX, etc.[8]. For this research, we

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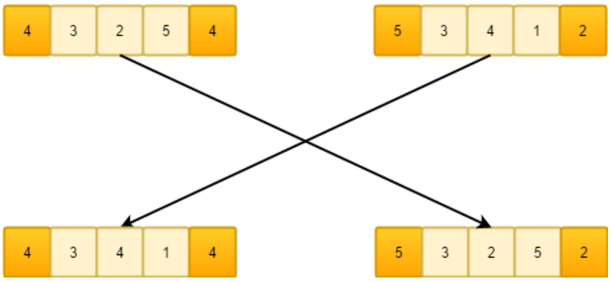

Figure. 2 The illustration of two-point crossover

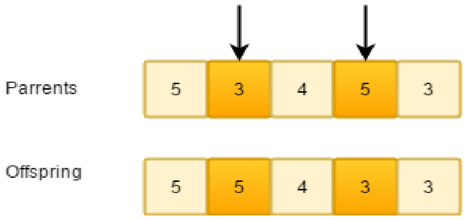

Figure. 3 The illustration of swap mutation operation

adopted the two-point crossover technique, as illustrated in Fig. 2 [22]. The following process explains the steps of the crossover operation.
Step 1: Choose two parents arbitrarily for crossover.
Step 2: Randomly determine two points
Step 3: Exchange the substring between these two points.

3.3 Selection strategy

The last stage of the GA process is the selection strategy to determine the chromosomes for the next generation. This stage adopted the elitist selection method. The *pop_size* best chromosomes (the highest fitness value) are chosen for the next generation.

3.4 Local search

Genetic algorithms (GA) function as a global search technique; however, it may often take a relatively long computational time to converge for a global optimum [24]. To solve this, many researchers suggested hybridizing GA with the local search technique. In this research, we developed a new and simple local search technique called Switching Local Search (SLS). It is done by first selecting a gene in the chromosome and changing its value randomly. The following Algorithm 1 illustrates the overall description of the proposed algorithms.

Algorithm 1: GAs for mm-KP
Input: data for the mm-KP test problem
Output: the best solution
Genetic Algorithm {
    Generate Initial population P(t);
    Evaluation Initial population P(t);
  Penalty strategy;
  While (not STOPPING CONDITION)
    Crossover;
    Mutation;
    Evaluation;
    (Penalty/Repairing strategy);
    Selection;
    Local Search Best chromosome P(t);
    P = P(t+l);
  }
}

It is shown that two different strategies are used to handle an infeasible chromosome resulted in crossover and mutation operations. The first strategy includes a procedure to repair the infeasible chromosome. The second strategy applies the penalty value for the infeasible chromosome. As mm-KP is the maximization problem, the penalty value will decrease the objective value. Thus, it will reduce the opportunity of the chromosome to be selected for the next generation. The local search procedure was included in the GA loop and implemented to the best chromosome to improve the solution quality.

4. Experimental design and results

4.1 Experimental design

To evaluate the effectiveness of the algorithms, several experimental studies have been conducted on 13 (thirteen) different size Benchmark instances taken from OR-Library. The test problems were divided into 3 (three) groups according to the size; small size (I01-I06), medium (I07-I09), and large (I10-I13). The number of variables in these 13 test problems varies from 25 to 4000. The detail of the

Table 3. Details of the instances, where n denotes the number of classes, r_i is the number of items in each group, and m is the number of resources

No.	Test problem	Data				Parameter	
		N	r_i	***m***	R_k	***Pop _size***	***Max _gen***
1	I01	5	5	5	25	50	1000
2	I02	10	5	5	50	50	1500
3	I03	15	10	10	75	50	2000
4	I04	20	10	10	100	100	1000
5	I05	25	10	10	125	100	1500
6	I06	30	10	10	150	100	2000
7	I07	100	10	10	500	200	1000
8	I08	150	10	10	750	200	1500
9	I09	200	10	10	1000	250	2000
10	I10	250	10	10	1250	300	1000
11	I11	300	10	10	1500	300	1500
12	I12	350	10	10	1750	450	2000
13	I13	400	10	10	2000	500	2000

Table 4. Performance of the GA approaches on all instances (SD: Standard Deviation)

Dataset	Optimum	sr-GA			hp-GA			hr-GA		
		Best	**Average**	**SD**	**Best**	**Average**	**SD**	**Best**	**Average**	**SD**
I01	173	**173**	173	0	**173**	170	2.9	**173**	173	0
I02	364	**364**	351	6.7	355	346.1	5.2	**364**	361	0.9
I03	1602	1536	1502.5	15.9	1556	1518	14.5	**1600**	1552.5	28.7
I04	3597	3433	3380.8	32.5	3488	3410	39.2	**3571**	3541.4	22
I05	3905.7	3900.4	3800.8	103	3905.7	3892	26.9	**3905.7**	3902	2.6
I06	4799.3	4787.2	4698.3	72.6	4799.3	4769.9	30.5	**4799.3**	4796	4.2
I07	24587	23071	22997.8	39.7	23717	23627	51.1	**23870**	23541.1	79.2
I08	36877	35536	34819.8	345.1	35547	32933	7764	**35626**	34932.4	90.2
I09	49167	47309	46237.6	540.7	47415	45946	748.1	**47370**	47338.1	43.8
I10	61437	58876	57826	568	59226	58898	245.1	**59228**	59056	40.3
I11	73773	70706	70557.3	142.1	70724	66620	1724.7	**71021**	70782.5	99.4
I12	86071	82089	89510.1	212	82305	77908	1195.6	**82627**	82342.8	104.5
I13	98429	94006	93478	279.2	94116	88429	1319.2	**94570**	94321.2	163

sr-GA: standard repairing-based GA (without local search)
hr-GA: hybrid repairing-based GA
hp-GA: hybrid penalty-based GA

test problems used for the experiments is shown in Table 3.

4.2 Results and discussion

A total of three GA approaches were developed, namely standard repairing GA (sr-GA), hybrid penalty-based (hp-GA), and hybridized penalty-based GA (hp-GA) by using Mathlab R2015b and run on PC Processor intel® Core ™i5-3470S. For the experiments, we set the values of crossover probability and mutation probability as 0.4 and 0.2, respectively. Each algorithm is run 20 (twenty) times for each test problem.

Table 4 summarizes the overall results of the experiments, where the best and the average values represent the best and the average fitness value from the 20 (twenty) running times. Standard deviation (SD) is the distribution of statistical measures of the data distribution. Optimum is the best-obtained solution in the literature. The results highlight that repairing-based GA has better performance than penalty-based GA. Due to the difficulties in generating feasible chromosomes, the penalty strategy cannot give good results for all of the test problems. In addition, many offspring, which led to GA operations is also infeasible. It can be seen from these results that combining GA with the local search will improve the solution quality immensely. The overall results show that hr-GA has better performance to solve mm-KP all of the time.

To assess the merit and limit of the proposed approach, we compare the performance of the new hr-GA to other heuristic algorithms available in the following literature: Moser [6], Heuristic [25], Modified-Reactive-Local-Search (MRLS) [9], Khan-Li-Manning-Akbar Algorithm (KLMA) [7], Derived algorithm [8], Ant Colony Algorithm [11], OSC Algorithm [12], SLS Algorithm [13] and AMMKP algorithm [14].

Table 5 summarizes the comparison of the results obtained by the heuristic algorithms. Similarly, in this Table, we also indicate our achievements that have the values greater than or equal to the best-published results in bold. These results show that hr-GA tends to reach optimal/near-optimal solutions to the problem. It can obtain the number of solution that better than or equal to the best solution in 5 cases among 13 cases, which better or same as the results given by Moser (1 case), Heuristic (1 case), RLS (4 cases), KLMA (2 cases), Derived Algorithm (2 cases), Ant Colony algorithm (5 cases), OSC algorithm (4 cases), SLS algorithm (6 cases) and AMMKP (11 cases).

In this research, we calculate the percentage error value for each instance by using the following formula:

$$Error = \frac{best - optimum}{optimum} \ x \ 100\% \quad (5)$$

The error comparisons of the heuristic methods for each test problem are illustrated in Figure 4. It shows that hr-GA can obtain good quality and reach optimal/optimal solution to the problem most of the time.

In this research, we also analyze the algorithm based on the average errors given by the methods for

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Table 5. Results of some heuristic methods on all mm-KP instances

Dataset	Optimum	Moser	Heuristic	RLS	KLMA	Der_ Algo	Ant	OSC	SLS	AMMKP	hr-GA
I01	173	151	167	**173**	167	**173**	**173**	**173**	**173**	**173**	**173**
I02	364	291	354	**364**	354	356	**364**	**364**	**364**	**364**	**364**
I03	1602	1464	1533	1595	1533	1553	**1602**	1594	**1602**	1594	1600
I04	3597	3375	3437	3564	3437	3502	3569	3514	**3592**	**3592**	3571
I05	3905.7	**3905.7**	3899.1	**3905.7**	**3905.7**	3905.2	**3905.7**	**3905.7**	**3905.7**	**3905.7**	**3905.7**
I06	4799.3	4115.2	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**
I07	24857	23556	23912	24121	23912	23983	24159	24162	24311	**24310**	24170
I08	36877	35373	35979	36110	35979	36007	36240	36405	36463	36530	**36641**
I09	49167	47205	47901	48291	47901	48048	48367	48567	48580	**48711**	48191
I10	61437	58648	59811	60291	59811	60176	60475	60858	60661	**60911**	60228
I11	73773	70532	71760	72283	71760	72003	72558	73022	72778	**73200**	72003
I12	86071	82377	84141	84446	84141	84160	84707	85284	84889	**85338**	85015
I13	98429	94166	96003	96850	96003	96103	96834	97545	97082	**97744**	97050
#Best		**1**	**1**	**4**	**2**	**2**	**5**	**4**	**6**	**11**	**5**

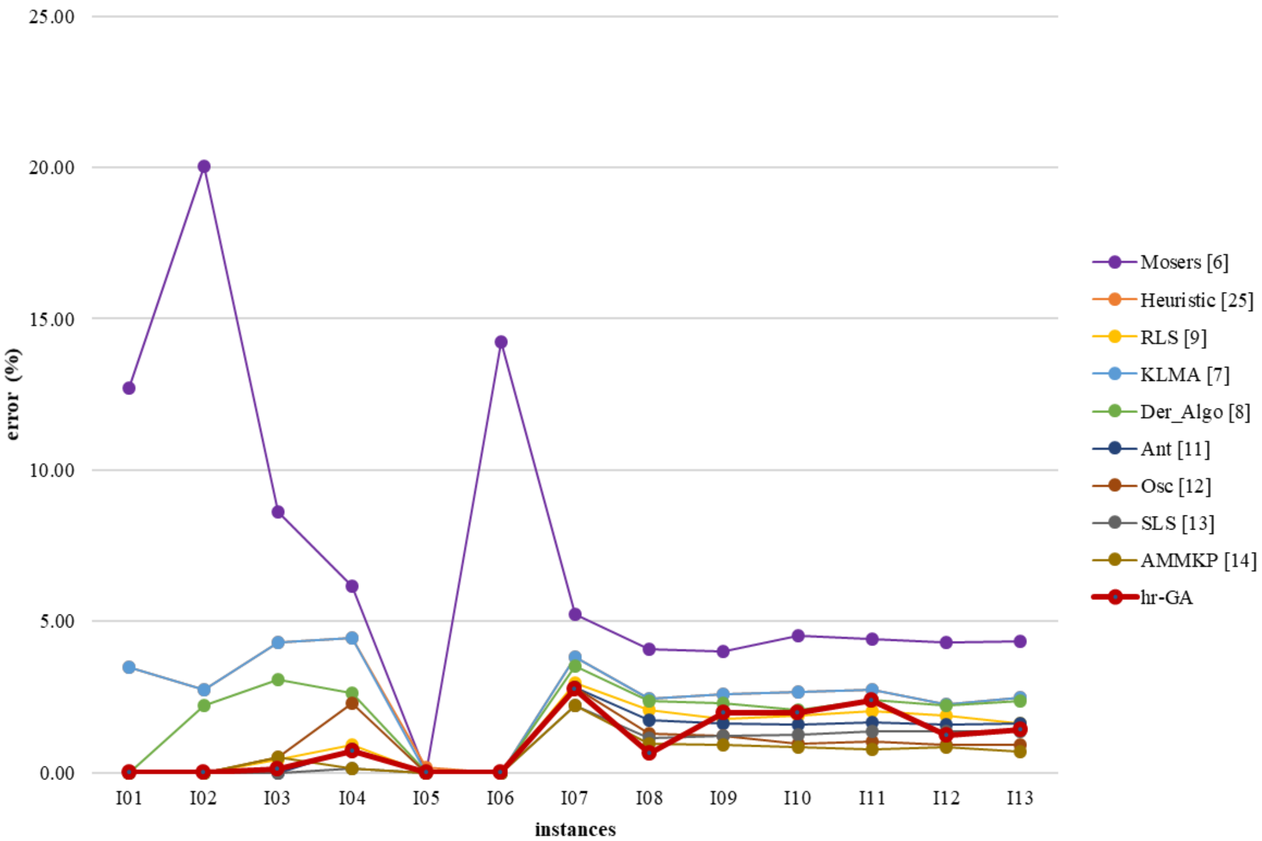

Figure 4. Error comparison between heuristic approaches on all mm-KP instances

those 13 test problems. The computation indicates that hr-GA provides competitive solutions with the average error equal to 1.02%, better than those obtained by Moser (7.13%), Heuristic (2.62%), RLS (1.2%), KLMA (2.6%), and Derived algorithm (1.93%), and the ant colony algorithm (1.03%). However, in comparison to the OSC algorithm (0.91%), SLS algorithm (0.77%), and AMMKP (0.61%), it still has a slightly larger average error. We illustrate the comparison of the average error for each method in the following Figure 5.

5. Conclusion

This paper analyzed three different GA approaches to solving mm-KP. The proposed methods adopt different strategies to handle

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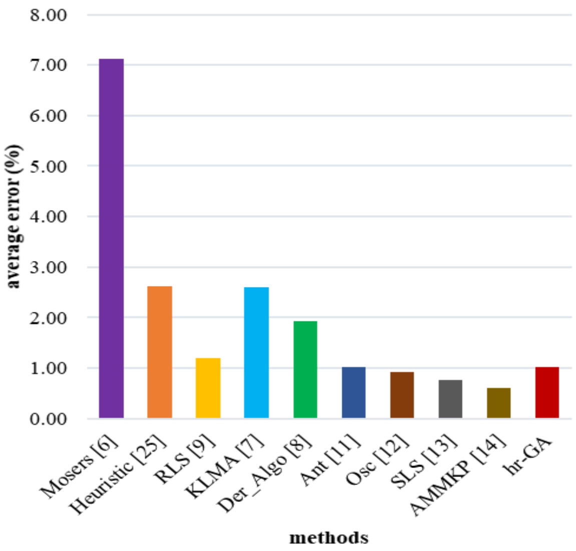

Figure 5. Comparison of the average errors between the heuristic methods

infeasible chromosomes, namely penalty and repairing procedure. Those are also hybridized a new simple local search technique to improve the solution quality. Several numerical experiments on a set of Benchmark instances taken from OR-Library have been conducted to evaluate the performance of the algorithms. The results show that repairing-based GA has better performance than penalty-based GA. Hybridizing GA with local search has also improved the solution quality immensely. The comparisons with other heuristic algorithms are also made based on the solution quality, the number of optimal solutions obtained, and average errors. It concludes that hr-GA is able to get competitive results with the other heuristics. These findings add to a growing body of literature on the applications of GA.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Mitsuo Gen gives the idea for the Algorithm; Admi Syarif and Dian Anggrainii designed the experiments; Dian Anggraini performed the experiments; Admi Syarif and Kurnia Muludi supervised the study, analyzed the results, verified the findings of the study, and wrote the paper.

Acknowledgments

The authors are grateful to "Hibah Unggulan" Lampung University, Grant-in-Aid No. 1514/UN26.21/PN/2020, 2020, for assisting this research. We thank the anonymous reviewers for their constructive comments that helped us a lot in substantially improving this paper.

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4
COVER LETTER JURNAL

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Paper Title	**Comparing Various Genetic Algorithm Approaches for Multiple-choice Multidimensional Knapsack Problem (mm-KP)**
Co-author(s)	**Dian Anggraini, Kurnia Muludi, Wamiliana and Mitsuo Gen**
Organisation	Department of Computer Science, Faculty of Mathematics and Sciences, Lampung University, Jl. S. Brodjonegoro No.1, Bandar Lampung, 35145
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5

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Gmail

ADMI SYARIF <admi.syarif@fmipa.unila.ac.id>

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ijies3205: Paper submission

4 messages

EGUCHI Kei <eguti@fit.ac.jp> Mon, May 11, 2020 at 11:39 AM
To: ADMI SYARIF <admi.syarif@fmipa.unila.ac.id>

Dear author(s),

Thank you for your interest and support to IJIES.
I am hereby to confirm the delivery of your paper, Paper ID is " ijies3205 ".
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From: ADMI SYARIF <admi.syarif@fmipa.unila.ac.id>
Sent: Monday, May 11, 2020 12:55 PM
To: ijies@inass.org; ADMI SYARIF <admi.syarif@fmipa.unila.ac.id>; Wamiliana Wamiliana <wamilianakhan@gmail.com>
Subject: Paper submission

May 12, 2020

Dear Chairman
First of all, we would like to appreciate your great work in managing this high-quality journal. It is our great pleasure to inform you that we would like to submit our full paper for consideration for publication on the International Journal of Intelligent Engineering and systems. We have made our paper following http://www.inass.org/share/IJIES_Format.docx. The current version paper has also been checked for the similarity by Turnitin (12 percent). We attach our full article and "Cover Letter" in this email.
Thank you very much for your assistance, and we look forward to hearing any comments and suggestions from you in the near future.

Sincerely Yours,

Admi Syarif, Ph.D. (Associate Professor)
Department of Computer Science
University of Lampung
Jl. S. Brodjonegoro No. 1, Bandar Lampung, 35145
INDONESIA
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EGUCHI Kei <eguti@fit.ac.jp> Wed, May 20, 2020 at 6:46 AM
To: ADMI SYARIF <admi.syarif@fmipa.unila.ac.id>

Dear author(s),

Congratulations!
The 1st review for your paper was accepted.
However, we are sorry to inform you that your paper cannot be recommended for publication in IJIES, in its current form.
Please revise your paper according to the attached reviewers' comments.

Please note that if your paper is still not satisfactorily revised or cannot be returned to us within TWO months from the date of this letter, your paper will not be recommended to the journal above.

Thanks for your understanding and cooperation.

Kind Regards,
IJIES Editors.

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ADMI SYARIF <admi.syarif@fmipa.unila.ac.id> Tue, May 26, 2020 at 10:53 AM
To: sketqo@gmail.com

Dear chairman

First of all, we would like to thank you for your quick response for our submission. We have received the review report of our paper. Now we are revising our the manuscript following the comments of the reviewer. We shall resubmit the revised version as soon as possible, Again thank you very much.

On Wed, May 20, 2020 at 11:47 AM ADMI SYARIF <admi.syarif@fmipa.unila.ac.id> wrote:
[Quoted text hidden]

ADMI SYARIF <admi.syarif@fmipa.unila.ac.id> Wed, Jul 15, 2020 at 9:56 AM
Draft To: EGUCHI Kei <eguti@fit.ac.jp>
Cc: ijies@inass.org

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6
REVIEW PERTAMA DARI REVIEWER JURNAL

Intelligent Networks and Systems Society

Review Form

International Journal of Intelligent Engineering and Systems (IJIES)

Paper ID	Ijies3205
Paper Title	Comparing Various Genetic Algorithm Approaches for Multiple-choice Multidimensional Knapsack Problem (mm-KP)

Recommendation for Publication	
□~~(Evaluation A:) Accept~~	□~~(Evaluation B:) Accept after Minor Revision~~
□(Evaluation C:) Accept after Major Revision	□~~(Evaluation D:) Reject~~

Comments from reviewers 1 & 2:

The novelty of this work is weak, because this is a comparison report between existing techniques. The finding of this research is small impact. Besides, the research survey of this work is thin. Nobody can understand the novelty of this work.

1. The research survey is not enough. The articles listed in References are old. (Most of them are out of date. In SCOPUS, the papers published within 3 years are used to calculate CiteScore.) The authors should survey past studies in detail.
2. The quotation of previous articles, such as [6-11], is rough. These citations are meaningless. You must quote articles properly.
3. There is no left-hand in Eq. (1).
4. The width of algorithm 1 is too wide.
5. This paper lacks in-depth discussions in Sect.4. The impact is lost by a short discussion of the findings. Readers will fail to understand the scientific contribution of this research. Show the theoretical reason why the proposed technique is better than existing techniques, because there is no theoretical explanation about compared existing techniques in previous sections. These existing techniques appeared suddenly in comparison. Explain the detail of the existing technique in previous sections.
6. Do not rotate the sheet of the paper. (see pp. 6-7.) Besides, unify the font size of tables to 10pt.
7. There is no Y-axis label in Figs. 4 and 5.
8. Eq. (5) has editing problems.
9. The results of this research are not clear in Conclusions. Furthermore, the benefits of the proposed method are not supported by theory. So, I fail to understand the scientific contribution of this research.
10. The results of this research are not clear in Conclusions. Show the scientific contribution of this work with concrete data.
11. Are there any more updated references, as the most newly one is in 2014, which needs to be updated?
12. Please improve the reference format. **This is very important for indexing service**. If you did not follow the following format, your paper will be rejected automatically.

    ***Do not use "et al." in author names.**

    e.g.

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International Conf. On Pattern Recognition, Vienna, Austria, pp.900-904, 1996.

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Please add “Conflicts of Interest” and “Author Contributions”. (see the IJIES format.docx)

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Declare conflicts of interest or state “The authors declare no conflict of interest.” Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results.

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	Technical depth	□Superficial □Suitable for the non-specialist □Appropriate for the generally knowledgeable individual working in the field □Suitable only for an expert
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7

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Answer to the reviewer comments

Title: Comparing of Various Genetic Algorithm Approaches for Multiple-choice Multidimensional Knapsack Problem (mm-KP)

Authors: Admi Syarif, Dian Anggraini, Kurnia Muludi, Wamiliana, and Mitsuo Gen

Dear reviewer 2

First of all, we would like to thank you for giving the opportunity to submit our revised manuscript, "Comparing Various Genetic Algorithm Approaches for Multiple-choice Multidimensional Knapsack Problem (mm-KP)" for publication in the *International Journal of Intelligent Engineering and Systems*. We greatly appreciate the time and effort that the reviewers dedicated to providing feedback on our manuscript. We found that those comments and advice have improved and enriched the quality of the paper immensely. We have incorporated most of the suggestions made by the reviewers. Those changes are highlighted in the manuscript. Please see below, in blue, for a point-by-point response to the reviewers' comments and concerns. We also have made the proof-reading by native-speaker and similarity check (Plagiarism) of the manuscript by using Turnitin (12 percent).

1. The research survey is not enough. The articles listed in the References are old. (Most of them are out of date. In SCOPUS, the papers published within three years are used d to calculate CiteScore.) The authors should survey past studies in detail.

   We agree with the reviewer's assessment. Accordingly, throughout the manuscript, we have revised the paper.
   - We have added past survey studies on the subject.
   - We have made more discussion on the problem.
   - We have added some recent references to this revised paper.

2. The quotation of previous articles, such as [6-11], is rough. These citations are meaningless. You must quote articles properly.

   - Following your recommendation, we have deleted the suggested references. We also have added several recent studies on the revised manuscript. We have made it clear the citations of the paper.

3. There is no left-hand in Eq. (1).

   - We are very sorry for our carelessness. We have modified our paper following this comment.

4. The width of algorithm 1 is too wide.

- We agree that this comment. Algorithm 1 has been modified following this suggestion.

5. This paper lacks in-depth discussions in Sect.4. The impact is lost by a short discussion of the findings. Readers will fail to understand the scientific contribution of this research. Show the theoretical reason why the proposed technique is better than existing techniques, because there is no theoretical explanation about compared existing techniques in previous sections. These existing techniques appeared suddenly in comparison. Explain the detail of the existing technique in previous sections.

- Thank you for pointing this out. We agree with your opinion. We have made a significant modification of the paper. More discussion on the existing algorithm has also been presented in Section 1. Section 3 gives a detailed explanation of the proposed approaches. In Section 4, we have a more detailed discussion on the experimental design and the finding results. We have made it clear the contribution of this research.

6. Do not rotate the sheet of paper. (see pp. 6-7.) Besides, unify the font size of tables to 10pt.

- As suggested by the reviewer, we have modified it in the manuscript.

7. There is no Y-axis label in Figs. 4 and 5.

- We are so sorry for this carelessness. The figures have been modified following this suggestion.

8. Eq. (5) has editing problems.

- Thank you for pointing this out. Eq. (5) has been updated

9. The results of this research are not clear in Conclusions. Furthermore, the benefits of the proposed method are not supported by theory. So, I fail to understand the scientific contribution of this research.

- Thank you very much. We have made significant revisions on the paper to make clear the contribution of this research. While we appreciate the reviewer's feedback, we think this study makes a valuable contribution to the field because :
  - This paper determines the best GA strategy to solve mm-KP.
  - In this paper, we developed a new simple local search and hybridized it into the GA loop to improve the quality of the solution.
  - This paper presents some comparisons of the proposed method with other Heuristic on the solution quality, average error, and the number of instances solved optimally.
  - The experimental results show that hr-GA has the merits of high effectiveness and can obtain competitive results with the other heuristics.
  - The conclusion has modified following your suggestion.

10. The results of this research are not clear in Conclusions. Show the scientific contribution of this work with concrete data.

● The revised manuscript has been modified following this suggestion. A more detailed explanation of the theory and experimental design have been provided to show the contribution of this work. Following this comment, we also have modified the conclusion. It would be our great pleasure if you can check the modification on the revised paper (See Table 4, Table 5, Table 5, Figure 4, and Figure 5 on the revised paper).

To assess the merit and limit of the proposed approach, we compare the performance of the new hr-GA to other heuristic algorithms available in the following literature: Moser [6], Hifi-Michrafy-Sbihi (HMS) [25], Modified-Reactive-Local-Search (MRLS) [9], Khan-Li-Manning-Akbar Algorithm (KLMA) [7], Der_Algorithm [26], Ant Colony Algorithm [11], OSC Algorithm [12], SLS Algorithm [13] and AMMKP algorithm [14].

The results indicate the achievements of the proposed method in comparison to the other heuristics. It is shown that hr-GA tends to reach optimal/near-optimal solutions (See Table 4, Table 5, Table 5, and Figure 4on the revised paper. It can obtain competitive results on the number of solution that better than or equal to the best solution in 5 cases among 13 cases, which better or same as the results given by Moser (1 case), Heuristic (1 case), HMS (2 cases), RLS (4 cases), KLMA (2 cases), Derivatives Algorithm (2 cases), Ant Colony algorithm (5 cases), OSC algorithm (4 cases), SLS algorithm (6 cases) and AMMKP (11 cases).

We summarize the comparison of the solution quality based on the average error for each test problem. These results indicate that hr-GA can obtain good quality and reach optimal/optimal solution. The also hr-GA provides better or competitive solutions with error on average equal to 1.02%, better than those obtained by Moser (7.13%), Heuristic (2.62%), HMS (2%), RLS (1.2%), KLMA (2.6%) and Derivatives Algorithm (1.93). Ant colony algorithm (1.03%), OSC algorithm (0.91%), SLS algorithm (0.77%) and AMMKP (0.61%).

●

s.

11. Are there any more updated references, as the most newly one is in 2014, which needs to be updated?

● Thank you very much. The revised manuscript has been modified following this suggestion. We have given some new references in the paper.

[1] S. Iqbal, M. F. Bari, and M. S. Rahman, "Solving the Multi-dimensional multi-choice knapsack problem with the help of ants", In: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, Berlin, Heidelberg, Vol. 6234, pp. 312–323, 2010.

[2] S. Htiouech, S. Bouamama, and R. Attia, "Using surrogate information to solve the multidimensional multi-choice knapsack problem", In: *Proc. of IEEE Congress on Evolutionary Computation*, Cancun, Mexico, pp. 2102–2107, 2013.

[3] Y. Xia, C. Gao, and J. L. Li, "A Stochastic Local Search Heuristic for the Multidimensional Multiple-choice Knapsack Problem", In: *Communications in Computer and Information Science*, Berlin, Heidelberg, Vol. 562, pp. 513–522, 2015.

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[7] M. Gen and L. Lin, “Multiobjective evolutionary algorithm for manufacturing scheduling problems: State-of-the-art survey”, *Journal of Intelligent Manufacturing*, Vol. 25, No. 5, pp. 849–866, 2014.

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Comparing Various Genetic Algorithm Approaches for Multiple-choice ~~Multidimensional~~Multi-dimensional Knapsack Problem (mm-KP)

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Abstract: One of the essential and well-known classes of combinatorial optimization problems commonly studies by researchers in the last five decades is called the Knapsack Problem (KP). Many variants of KP ~~formulation~~ have been introduced for different real-world applications~~, such as diet program, investment plan, cargo, stock, etc. However, among these variants~~. Among them, the multiple-choice ~~multidimensional~~multi-dimensional Knapsack Problem (mm-KP) is the most complex model with an NP-hard problem. Several authors have reported the robustness of heuristics for mm-KP; irrespective of its advantages, no method currently has the ability to solve the problem optimally all time.

~~The main objective of this research is~~ This paper aims to determine the best GA strategy and evaluate the performance of ~~three~~several heuristic algorithms to solve mm-KP. We investigate the use of two techniques that are included in the GA approach. The first, two different ~~Genetic Algorithm (GA) approaches for solving mm-KP. The first is a standard~~strategies are adopted to handle infeasible chromosomes, namely penalty and repairing ~~based GA (sr-GA), followed by the hybridized repairing-based GA (hr-GA) that combines the~~ procedure. Second, we develop a new simple local search ~~technique to the repairing-based GA. Finally, a hybridized penalty-based GA (hp-GA) was developed using~~to improve the ~~local search technique. The proposed approaches are computationally analyzed through intensive numerical experiments~~quality of the solution found. Experimental studies on ~~a~~the 13 (thirteen) Benchmark instances ~~taken from OR-Library. Meanwhile, the algorithm is measured~~are conducted to evaluate the effectiveness of the approach based on solutions quality, the number of the optimal solution reached, and average errors. The results showed that hr-GA tends to reach optimal/near-optimal solutions ~~within reasonable computational time.~~ Furthermore, the results from studies on heuristic algorithms also show that hr-GA is a promising approach, with local search used to immensely improve the quality.

Keywords: repairing strategy, local search, heuristic method, Genetic Algorithm, Knapsack Problem.

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1. Introduction

In 1950, Dantzig introduced the classical Knapsack Problem (KP), which is one of the famous optimization problems. It represents the subsets of the *n* items and ensures that the total weight of the Knapsack capacity is not exceeded while maximizing the corresponding profit. Practical applications of classical KP can be found in some of our daily life, such as the everyday diet program, an optimal investment plan, cargo loading, cutting stock, budget control, and financial management [1].

Several variations of KP have been previously discussed. These include multiple-choice Knapsack Problem (mc-KP) [1], multidimensional Knapsack Problem (md-KP) [2], and multiple-choices multidimensional Knapsack Problem (mm-KP) [3], as the most complex and NP-hard problem. It is considered as a combination of mc-KP and md-KP cases. mm-KP has many real-life applications, which include Chip Multiprocessor Run-time Resource Management [3], Global Routing of Wiring in Circuits [4], and Service Level Agreement [5]. Due to its high complexity, several studies introduced heuristic approaches to solve their problems. However, none of the methods has the ability to solve mm-KP optimally all time.

One of the popular heuristic methods used over the past few decades is the Genetic Algorithm (GA) [5]. This method rapidly evolves the solutions of many hard optimization problems. Previous studies have also shown the robustness of GA for many logistic optimization problems [6]-[11]. For some specific cases, however, it tends to provide local optimum and takes more time to reach optimal solutions. Therefore, it is crucial to carry out studies on designing an effective and efficient GA approach.

The most essential and influential component associated with the implementation of GA is the method used to represent the chromosome. For many combinatorial optimization problems, it is difficult to express the chromosome in a way capable of fulfilling the constraint functions. This is because the generated chromosome in the population is either feasible or infeasible. Two strategies are usually adopted to overcome the infeasible situation, namely repairing and penalty [12]. The first strategy includes a procedure to repair the infeasible chromosome. However, it is often challenging to develop this procedure for a specific problem. The second strategy is the penalty that applies the function/value for the infeasible chromosome. For the maximization problem, the penalty function decreases objective value and reduces the fitness value and opportunity selected for the next generation.

Another critical issue in the applications of GA is associated with the strategies used to quit the local-optimal solution. The most common strategy is to develop and hybridize GA with a local search technique. This strategy has been shown to improve the solution quality immensely [8].

The main objective of this research is to validate the performance of three different GA approaches to solve mmKP, namely standard repairing-based (sr-GA), hybrid repairing-based GA (hr-GA), and hybrid penalty-based GA (hp-GA). The numerical experiments are conducted by using 13 Benchmark test problems, taken from OR-Library. The performances of the algorithm are measured based on the solution quality and the average computational Time (ACT). The authors also compared the results to some heuristic methods [13]-[14].

This research is further organized

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1. Introduction

In 1950, Dantzig introduced the classical Knapsack Problem (KP), which is one of the famous combinatorial optimization problems. It represents the problem of selecting the subsets of the *n* items to maximize the corresponding profit, and the total weight does not exceed the Knapsack capacity. Practical applications of KP can be found in some of our daily life, such as the everyday diet program, an optimal investment plan, cargo loading, cutting stock, budget control, and financial management [1].

Different variants of KP are found in the literature, including, multiple-choice KP (mc-KP), multi-dimensional KP (md-KP), and multiple-choices multi-dimensional KP (mm-KP) [2]. Among them, mm-KP is the most complex belongs to the class of an NP-hard problem. It is considered as a variant of the md-KP where items are divided into groups, and precisely one item per group must be selected. The applications of mm-KP can be found in many real-life applications, including Chip Multiprocessor Run-time Resource Management [3], Global Routing of Wiring in Circuits [4], and Service Level Agreement [5].

The methods proposed in the literature to solve mm-KP can be grouped into two classes: exact and heuristic methods. Since mm-KP is an NP-hard problem, its search space exponentially grows as the problem size increases. Therefore, many researchers pay more attention to develop heuristic methods to solve mm-KP. Although the heuristics do not guarantee the finding of an optimal solution, those have been reported useful in determining optimal/near-optimal solutions for many hard optimization problems, including mm-KP.

To our knowledge, the first heuristic algorithm to solve mm-KP was reported by Moser et al. [6]. The authors introduced a Lagrangian Relaxation algorithm that was repeatedly permuting to reduce the infeasibility of solutions. A heuristic algorithm based on aggressive resource usage was proposed by Khan et al. [7]. This heuristic algorithm performs better than Moser's Algorithm. Then, Hifi presented several approaches to solve mm-KP. First, Hifi et al. proposed a heuristic approach with a guided-local search that used the principle based on trying several diversified solutions obtained after penalizing the costs of the objective function with penalties parameters [8]. Hifi et al. also developed an algorithm based on a reactive local search to try a diversification search and to escape local optima [9]. The authors reported that their methods are able to outperform Moser's and Khan's algorithms.

Later, Cherfi and Hifi presented column generation methods hybridized with branch-and-bound [10]. They reported that the approaches could obtain better solutions than former approaches on the benchmark instances. An ant colony algorithm approach to solve mm-KP was given by Iqbal et al. [11]. A heuristic method called oscillation (OSC Algorithm) was introduced by Htiouech et al. [12]. The authors used the constraint normalization method to improve the quality of solutions. Xia et al. developed another similar approach to the OSC algorithm, called Stochastic Local Search (SLS) [13]. The algorithm adopted a simple additive weighting scheme to adjust the weight (multiplier) on dimensions.

In one latest paper, Htiouech and Alzaidi proposed a heuristic algorithm called AMMKP [14]. The authors presented the way to decompose the mm -KP into many smaller sub-problems, and each subproblem then solved by an agent. The results show that the approach is able to solve several benchmark instances in the literature effectively.

Since Holland introduced it in 1975 [15], the Genetic Algorithm (GA) has been a prevalent heuristic method. Previous studies have shown the robustness of GA for various hard optimization problems, including the logistic problem [16] [17], scheduling problem [18], vehicle routing problem [19], and so on. For some specific cases, however, it often tends to provide local optimum and takes more time to reach optimal solutions. Therefore, it is crucial to carry out studies on designing an effective and efficient GA approach.

The most essential and influential component associated with the implementation of GA is the method used to represent the chromosome. For many optimization problems, it is difficult to express the chromosome in a way capable of fulfilling the constraint functions. This is because the generated chromosome in the population is either feasible or infeasible. Two strategies are usually adopted to overcome the infeasible situation, namely repairing and penalty [20]. Another critical issue in the applications of GA is associated with the strategies used to quit the local-optimal solution. The most common approach is to develop and hybridize GA with a local search technique [21].

This paper aims to determine the best GA strategy to solve mm-KP. To improve the quality of the solution, we developed a new simple local search and hybridized it into the GA loop. The approaches adopt both repairing and penalty strategy, namely as repairing-based (sr-GA), hybrid repairing-based GA (hr-GA), and hybrid penalty-based GA (hp-GA). Furthermore, some comparisons with other heuristic methods are also made based on the solution quality, average error, and the number of instances solved optimally.

To evaluate the approaches, we conducted some numerical experiments on set Benchmark test problems taken from OR-Library. The 13 (thirteen) widely studied instances are used to measure the performances of the algorithms. The experimental results show that hr-GA has the merit of high effectiveness and can obtain competitive results with the other heuristics.

We organize this paper into five sections. The second outlines the mathematical formulation of mm-KP. The ~~third presents~~ brief designs of the proposed ~~algorithm, which includes~~algorithms, including the chromosome representation ~~of chromosome~~, genetic operation, and local search technique~~.~~, are presented in the third section. The numerical experiments and the ~~comparative~~comparison of results ~~of~~to other methods are described in the fourth section. Finally, conclusions are drawn in the last ~~session~~part.

2. Mathematical Model and Algorithm

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i	index of class
j	index of item
k	index of resource
R_k	resource constraint $R = R_1, R_2, R_3, \dots, R_m$
r_{ij}^k	the need for the k^{th} resource for the j^{th} item in the i^{th} class

~~This research~~mm-KP aims to fill one item from each class of Knapsack in order to satisfy the resource capacity constraints and maximize the total profit values. ~~The~~Formally the mathematical formulation of mm-KP ~~is~~can be written as follows:

$$\max Z = \sum_{i=1}^{n} \sum_{j=1}^{r_i} x_{ij} v_{ij} \quad (1)$$

s.t.

$$\sum_{i=1}^{n} \sum_{j=1}^{r_i} r_{ij}^k x_{ij} \leq R_k, k \in \{1 \dots, m\} \quad (2)$$

$$\sum_{j=1}^{r_i} x_{ij} = 1, i \in \{1, \dots n\} \quad (3)$$

$$x_{ij} \in \{0,1), i \in \{1, \dots n\}, j \in \{1, \dots r_i\} \quad (4)$$

~~with~~

~~v_{ij} The profit value of item j in the i-th class~~

~~In the above model~~

Here, the value of x_{ij} is either 1 or 0, which implies that item j in the i-th class is chosen, or not chosen. The v_{ij} represents the profit value of item j in the i-th class.

3. Design of the ~~Algorithm~~Algorithms

3.1 Chromosome Representation and Evaluation

~~The~~ When implementing GA for a specific application, the first step ~~in the GA process is~~is to determine a way to represent a possible solution to the problems. We have to generate some feasible chromosomes, which is as much as the desired population size. ~~The number of classes has the ability to significantly affect the size of the specified population. For the mm-KP, the number of gen on the~~For this research, we represent chromosome by using a string, that its length is equal to the number of classes~~(i)~~. For example, the ~~following~~ dataset I01 comprises of five groups (i), five items (j), and five resources (k) in each class, ~~respectively~~ with a resource constraint (R_k) of 25. ~~The data for this instance (I01) is as follows:~~

~~1~~

~~7.00 1 3 1 1 6~~
~~17.00 1 4 9 9 3~~
~~25.00 4 3 9 8 2~~
~~35.00 4 5 8 0 6~~
~~36.00 6 8 3 0 7~~
~~2~~
~~9.00 0 0 4 4 2~~
~~10.00 0 0 1 8 7~~
~~10.00 1 1 6 0 6~~
~~39.00 9 1 2 2 4~~
~~44.00 8 7 0 8 2~~
~~3~~
~~15.00 2 0 5 5 5~~
~~19.00 2 3 2 6 2~~
~~20.00 3 1 6 4 7~~
~~44.00 6 7 5 6 9~~
~~50.00 9 5 9 2 2~~
~~4~~
~~5.00 0 1 3 8 0~~
~~25.00 2 2 7 0 8~~
~~32.00 5 5 6 1 9~~
~~37.00 6 3 6 9 1~~
~~37.00 7 9 7 2 3~~
~~5~~
~~24.00 4 0 7 0 2~~
~~30.00 4 8 9 0 0~~
~~32.00 5 2 7 2 0~~
~~43.00 5 5 9 5 2~~
~~44.00 9 2 2 2 3~~

The chromosome representation for this instance ~~is shown~~I01 can be illustrated in Figure 1. The data for this instance (I01) is as follows:

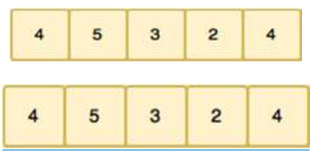

Figure 1~~:~~. Chromosome representation for instance I01

Table 1. Data for IO1 Instance

1					
7	1	3	1	1	6
17	1	4	9	9	3
25	4	3	9	8	2
35	4	5	8	0	6
36	6	8	3	0	7
2					

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9	0	0	4	4	2
10	0	0	1	8	7
10	1	1	6	0	6
39	9	1	2	2	4
44	8	7	0	8	2
3					
15	2	0	5	5	5
19	2	3	2	6	2
20	3	1	6	4	7
44	6	7	5	6	9
50	9	5	9	2	2
4					
5	0	1	3	8	0
25	2	2	7	0	8
32	5	5	6	1	9
37	6	3	6	9	1
37	7	9	7	2	3
5					
24	4	0	7	0	2
30	4	8	9	0	0
32	5	2	7	2	0
43	5	5	9	5	2
44	9	2	2	2	3

In the above chromosome, the index represents the class, while the value item gene is used to represents the item index j in each class i. From the chromosome, the selected items are 4, 5, 3, 2, and 4 in the 1st, 2nd, 3rd, 4th, and 5th classes, respectively.class. The decoding mechanism is done by selecting one item for each category. The number of resource consumption (r_{ijk}) of each item is used to check for the resource constraint. Here, the total value of r_{ijk} cannot exceed the (R_k) amount of each class, as shown in Table 2.

The decoding process of a chromosome is conducted by calculating the value of the goods (profit) and resource needs for each gene resource in order to exceed the resource constraint on each dataset. The decoding mechanism is carried out by selecting an item for each category such that the total value of the r_{ijk} does not exceed the amount of R_k.

The use of data, on the number of resource consumption (r_{ijk}) of each item is used to check for the resource constraint. Here, the total value of r_{ijk} does not exceed the (R_k) amount of each class, as shown in Table 2.

Table 2: Chromosome Decoding

Table 2. The decoding of the chromosome

	4	5	3	2	4
r_{ij1}	4	8	3	2	5
rij_2	5	7	1	2	5
r_{ij3}	8	0	6	7	9
r_{ij4}	0	8	4	0	5
r_{ij5}	6	2	7	8	1
R_k	23	25	21	19	25

3.2 Crossover and Mutation

In the GA process, two genetic operations known as crossover and mutation are usually used to involve the new solution space. The crossover operation is used to produce new offspring by recombining gen between selected parents. When choosing the crossover method, chromosome representation is considered. There are several variants of crossover methods introduced in the literature, such as one-point, two-point, PMX, WMX, etc. [14]. However, this adopted the two-point crossover technique [15]. The process is shown in the following steps:

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When implementing GA, two genetic operations are usually used to involve the new solution space, namely as crossover and mutation. The crossover operation is used to produce new offspring by recombining gen between selected parents. When choosing the crossover method, we have to consider the chromosome representation. There are several variants of the crossover methods introduced in the literature, such as one-point crossover, two-point crossover, PMX, WMX, etc.[8]. For this research, we adopted the two-point crossover technique, as illustrated in Figure 2 [22]. The following process explains the steps of the crossover operation.

Step 1: Choose two parents arbitrarily for crossover.

Step 2: Randomly determine two points

Step 3: Exchange the substring between these two points.

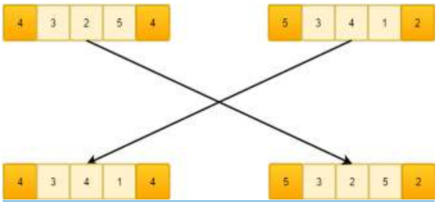
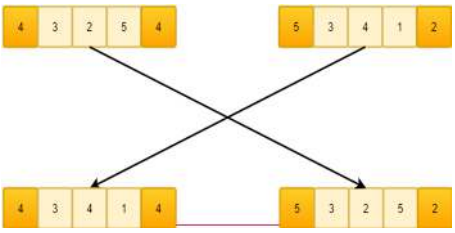
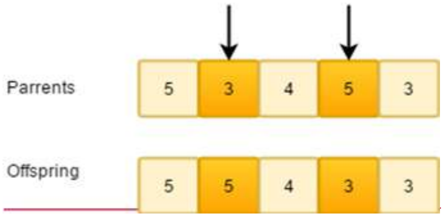


Figure ~~2 shows the~~2. The illustration of ~~the~~ two-point crossover~~.~~



~~**Figure 2:** Illustration of two-point Crossover~~

~~. The main objective of the mutation process is to prevent premature convergence to the local optimal by exchanging the information within a chromosome. Therefore, this research adopted the swap mutation technique by randomly selecting and interchanging two genes in the chromosome, as shown in Figure 3.~~



The main objective of the mutation is to prevent premature convergence to the local optimal. It is usually done by exchanging the information within a chromosome. There are also several variants of mutation strategies for different chromosome representations, including inversion mutation, displacement mutation, swap mutation, and so on [23]. We used the swap mutation technique by randomly selecting and interchanging two genes in the chromosome, as shown in Figure 3.

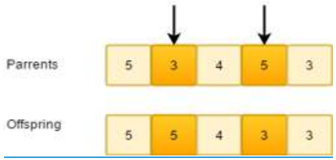


Figure 3~~: Illustration~~. The illustration of swap mutation operation

3.3 Selection Strategy

The last stage of the GA process is the selection strategy~~, which is used~~ to determine the ~~chromosome~~chromosomes for the next generation. This stage ~~used~~adopted the elitist ~~approach for~~ selection~~, with the next~~ method. The *pop_size* best chromosomes ~~chosen based on~~ (the highest fitness value) are chosen for the next generation.

3.4 Local Search

~~Genetic algorithms (GAs) function as a global search technique; however, they may often take a relatively long time to converge for a global optimum [16]. Therefore, hybridizing GA, with the local search, is the right choice to obtain a better solution. This paper used a novel, simple, and efficient local search technique by selecting a gene in the chromosome and changing its value randomly. This local search procedure was implemented to the best chromosome in the population, using the maximum generation as the stopping condition. The overall description of~~

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~~the proposed algorithm is illustrated in the following Algorithm 1.~~

Genetic algorithms (GA) function as a global search technique; however, it may often take a relatively long computational time to converge for a global optimum [24]. To solve this, many researchers suggested hybridizing GA with the local search technique. In this research, we developed a new and simple local search technique called Switching Local Search (SLS). It is done by first selecting a gene in the chromosome and changing its value randomly. The following Algorithm 1 illustrates the overall description of the proposed algorithms.

Algorithm 1: GAs for mm-KP
Input: ~~Data~~data for the mm-KP test problem
Output: the best solution

```
Genetic Algorithm {
    Generate Initial population P(t);
    Evaluation Initial population P(t);
   Penalty strategy;
  While (not STOPPING CONDITION) {)
    Crossover;
    Mutation;
    Evaluation;
    (Penalty/repairingRepairing strategy);
    Selection;
    Local Search Best chromosome P(t);
    P = P(t+1);
 }
}
```

It is shown that two different strategies are used to handle an infeasible chromosome resulted in crossover and mutation operations. The first strategy includes a procedure to repair the infeasible chromosome. The second strategy applies the penalty value for the infeasible chromosome. As mm-KP is the maximization problem, the penalty value will decrease the objective value. Thus, it will reduce the opportunity of the chromosome to be selected for the next generation. The local search procedure was included in the GA loop and implemented to the best chromosome to improve the solution quality.

4. Experimental Design and ~~Discussion~~Results

4.1 Experimental Design ~~of The Experiments~~

To evaluate the effectiveness ~~and efficiency~~ of the algorithms, several ~~experiments were~~experimental studies have been conducted on 13 (thirteen) different size Benchmark instances taken from OR-Library ~~http://cermsem.univ-paris1.fr/pub/~~. The test problems were divided into 3 (three) groups~~,~~ according to the size~~. Those are~~; small size (I01-I06), medium (I07-I09), and large (I10-I13). The number of variables in these 13 ~~instances~~ test problems varies from 25 to 4000. ~~Table 3 shows the~~ The detail of the test problems ~~and GA parameter values~~ used for the experiments~~.~~ is shown in Table 3.

Table 3~~:~~. Details of the instances, where *n* denotes the number of classes, r_i is the number of items in each group, and *m* is the number of resources

No.	~~Dataset~~Test problem	Data: N	Data: ~~r_t~~ r_i	Data: m	Data: R_k	Parameter: ~~pop~~Pop size	Parameter: ~~max~~Max gen
1	I01	5	5	5	25	50	1000
2	I02	10	5	5	50	50	1500
3	I03	15	10	10	75	50	2000
4	I04	20	10	10	100	100	1000
5	I05	25	10	10	125	100	1500
6	I06	30	10	10	150	100	2000
7	I07	100	10	10	500	200	1000
8	I08	150	10	10	750	200	1500
9	I09	200	10	10	1000	250	2000
10	I10	250	10	10	1250	300	1000
11	I11	300	10	10	1500	300	1500
12	I12	350	10	10	1750	450	2000
13	I13	400	10	10	2000	500	2000

4.2 Results and Discussion

A total of three GA approaches were developed, namely standard repairing GA (sr-GA), hybrid penalty-based (hp-GA), and hybridized penalty-based GA (hp-GA) by using Mathlab R2015b and run on PC Processor intel® Core ™i5-3470S. For the experiments, we set the values of crossover probability and mutation probability ~~are set to~~as 0.4 and 0.2, respectively. ~~For each test problem, the~~Each algorithm is run 20 (twenty) times~~.~~
~~Table 3~~ for each test problem.

Table 4 summarizes the overall results of the experiments, where the best and the ~~worst~~average values ~~are used to~~ represent the best and the average fitness value from the 20 (twenty) running times. Standard ~~Deviation~~deviation (SD) is the ~~measure of the~~ distribution of ~~statistics~~statistical measures of the data distribution ~~of data~~. Optimum is the best-obtained solution in the literature. The results highlight that repairing-based GA has better performance than penalty-based GA. ~~This is due~~Due to the difficulties ~~of GA~~ in generating feasible

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chromosomes., the penalty strategy cannot give good results for all of the test problems. In addition, many offspring, which led to GA operations is also infeasible. The result also showsIt can be seen from these results that combining GA with the local search immenselywill improve the solution quality. immensely. The overall results show that hr-GA has better performance to solve mm-KP all of the time.

To assess the merit and limit of the proposed approach, we compare the performance of the new hr-GA to other heuristic algorithms available in the following literature: Moser [6], Heuristic [25], Modified-Reactive-Local-Search (MRLS) [9], Khan-Li-Manning-Akbar Algorithm (KLMA) [7], Derived algorithm [8], Ant Colony Algorithm [11], OSC Algorithm [12], SLS Algorithm [13] and AMMKP algorithm [14].

~~To obtain more information, the solution quality is compared to some methods in the following literatures, Upper Bound [13], Moser [17], HMS [18], Reactive Local Search (RLS) [19], Modified Reactive Local Search (MRLS) [19], Khan (KLMA) [20], Der Algo [14]. Table 5 summarizes the comparison of the results obtained by the algorithms.~~

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Table 4. Performance of the GA Approaches on all instances (SD: Standard Deviation)

Dataset	**Optimum**	**~~r~~sr-GA**				**hp-GA**				**hr-GA**			
		Best	~~**Worst**~~	**Average**	**SD**	**Best**	~~**Worst**~~	**Average**	**SD**	**Best**	~~***Worst***~~	**Average**	**SD**
I01	173~~.0~~	**173**~~.0~~	**173**~~.0~~	173~~.0~~ ~~173.0~~	~~0.~~0	**173**~~.0~~	~~167.0~~	170~~.0~~	2.9	**173**~~.0~~	**173**~~.0~~	173~~.0~~ ~~173.0~~	~~0.~~0
I02	364~~.0~~	**364**~~.0~~	~~344.0~~	351~~.0~~	6.7	355~~.0~~	~~336.0~~	346.1	5.2	**364**~~.0~~	**364**~~.0~~	361~~.0~~ ~~361.0~~	0.9
I03	1602~~.0~~	1536~~.0~~	~~1481.0~~	1502.5	15.9	1556~~.0~~	~~1498.0~~	1518~~.0~~	14.5	**1600**~~.0~~	~~1518.0~~	1552.5	28.7
I04	3597~~.0~~	3433~~.0~~	~~3326.0~~	3380.8	32.5	3488~~.0~~	~~3331.0~~	3410~~.0~~	39.2	**3571**~~.0~~	~~3507.0~~	3541.4	22~~.0~~
I05	3905.7	3900.4	~~3617.0~~	3800.8	103~~.0~~	~~3906.0~~3905.7	~~3824.0~~	3892~~.0~~	26.9	**3905.7**	~~3900.4~~	3902~~.0~~	2.6
I06	4799.3	4787.2	~~4547.6~~	4698.3	72.6	4799.3	~~4688.7~~	4769.9	30.5	**4799.3**	~~4786.6~~	4796~~.0~~	4.2
I07	24587~~.0~~	23071~~.0~~	~~22979.0~~	22997.8	39.7	23717~~.0~~	~~23524.0~~	23627~~.0~~	51.1	**23870**~~.0~~	~~22979.0~~	23541.1	79.2
I08	36877~~.0~~	35536~~.0~~	~~34500.0~~	34819.8	345.1	35547~~.0~~	~~3451.0~~	32933~~.0~~	7764~~.0~~	**35626**~~.0~~	~~34573.0~~	34932.4	90.2
I09	49167~~.0~~	47309~~.0~~	~~47285.0~~	46237.6	540.7	47415~~.0~~	~~45030.0~~	45946~~.0~~	748.1	**47370**~~.0~~	~~47285.0~~	47338.1	43.8
I10	61437~~.0~~	58876~~.0~~	~~58876.0~~	57826~~.0~~	568~~.0~~	~~5926.0~~59226	~~58239.0~~	58898~~.0~~	245.1	**59228**~~.0~~	~~58919.0~~	59056~~.0~~	40.3
I11	73773~~.0~~	70706~~.0~~	~~70686.0~~	70557.3	142.1	70724~~.0~~	~~67242.0~~	66620~~.0~~	1724.7	**71021**~~.0~~	~~70686.0~~	70782.5	99.4
I12	86071~~.0~~	82089~~.0~~	~~82013.0~~	89510.1	212~~.0~~	82305~~.0~~	~~78137.0~~	77908~~.0~~	1195.6	**82627**~~.0~~	~~82013.0~~	82342.8	104.5
I13	98429~~.0~~	94006~~.0~~	~~93125.0~~	93478~~.0~~	279.2	94116~~.0~~	~~88802.0~~	88429~~.0~~	1319.2	**94570**~~.0~~	~~940636.0~~	94321.2	163~~.0~~

sr-GA: standard repairing-based GA (without local search)
hr-GA: hybrid repairing-based GA
hp-GA: hybrid penalty-based GA

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~~**Table 5** Comparative results of some heuristic methods for solving mm-KP~~

Table 5 summarizes the comparison of the results obtained by the heuristic algorithms. Similarly, in this Table, we also indicate our achievements that have the values greater than or equal to the best-published results in bold. These results show that hr-GA tends to reach optimal/near-optimal solutions to the problem. It can obtain the number of solution that better than or equal to the best solution in 5 cases among 13 cases, which better or same as the results given by Moser (1 case), Heuristic (1 case), RLS (4 cases), KLMA (2 cases), Derived Algorithm (2 cases), Ant Colony algorithm (5 cases), OSC algorithm (4 cases), SLS algorithm (6 cases) and AMMKP (11 cases).

Table 5. Results of some heuristic methods on all mm-KP instances

Data set	~~Upper Bound~~	Optimum	~~Moser~~ Moser	Heuristic	~~HMS~~	RLS	~~MRLS~~	KLMA	Der_Algo	~~hp-GA~~ Ant	~~r-GA~~ OSC	SLS	AMMKP	~~Hr~~hr-GA	~~GA*~~
I01	~~182.71~~	173	151.~~0~~	167.~~0~~		**173**.~~0~~		~~173.0~~167	**173**.~~0~~ ~~167.0~~	**173**.~~0~~	**173**.~~0~~	**173**.~~0~~	**173**.~~0~~	**173**.~~0~~	
I02	~~365.80~~	364	291.~~0~~	354.~~0~~	~~356.0~~	**364**.~~0~~	~~364.0~~	354.~~0~~	356.~~0~~	~~355.0~~**364**	**364**.~~0~~	**364**.~~0~~	~~361.0~~**364**	**364**	
I03	~~1626.59~~	1602	1464.~~0~~	1533.~~0~~	~~1553.0~~	1595.~~0~~	~~1602.0~~	1533.~~0~~	1553.~~0~~	1602~~1556.0~~	~~1529.0~~ 1594	**1602**	1594	1600.~~0~~	~~1598.0~~
I04	~~3631.60~~	3597	3375.~~0~~	3437.~~0~~	~~3502.0~~	3564.~~0~~	~~3597.0~~	3437.~~0~~	3502.~~0~~	~~3488.0~~ 3569	~~3433.0~~ 3514	**3592**	**3592**	3571.~~0~~	~~3591.0~~
I05	~~3905.90~~	3905.7	**3905.7**	3899.1	~~3868.2~~	**3905.~~9~~7**		**3905.7** ~~3899.1~~	3905.2	~~390.0~~**3905.7**	~~3900.4~~**3905.7**	**3905.7**	**3905.7**	**3905.7**	
I06	~~4812.82~~	4799.3	4115.2	**4799.3**		**4799.3**		**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3** ~~4787.2~~	**4799.3**	**4799.3**	
I07	~~24607.95~~	24857	23556.~~0~~	23912.~~0~~	~~23983.0~~	24121.~~0~~	~~24587.0~~	23912.~~0~~	23983.~~0~~	~~23717.0~~24159	~~23905.7~~24162	24311	**24310**	24170.~~0~~	~~24423.0~~
I08	~~36904.41~~	36877	35373.~~0~~	35979.~~0~~	~~36007.0~~	36110.~~0~~	~~36877.0~~	35979.~~0~~	36007.~~0~~	~~35543.0~~36240	~~35536.0~~36405	~~36641.0~~36463	36530	**36641**.~~0~~	
I09	~~49193.87~~	49167	47205.~~0~~	47901.~~0~~	~~48048.0~~	48291.~~0~~	~~49167.0~~	47901.~~0~~	48048.~~0~~	~~45261.0~~48367	~~47309.0~~48567	48580	**48711**	48191.~~0~~	~~48691.0~~
I10	~~61486.30~~	61437	58648.~~0~~	59811.~~0~~	~~60176.0~~	60291.~~0~~	~~61437.0~~	59811.~~0~~	60176.~~0~~	~~59276.0~~60475	~~58989.0~~60858	~~59228.0~~60661	~~60770.0~~**60911**	60228	
I11	~~73797.74~~	73773	70532.~~0~~	71760.~~0~~	~~72003.0~~	72283.~~0~~	~~73773.0~~	71760.~~0~~	72003.~~0~~	~~66726.0~~72558	~~70706.0~~73022	72778	**73200**	72003.~~0~~	~~72958.0~~

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I12	~~86100.45~~	86071	82377~~.0~~	84141~~.0~~	~~84160.0~~	84446~~.0~~	~~86069.0~~	84141~~.0~~	84160~~.0~~	~~82150.0~~84707	~~82089.0~~85284	~~85015.0~~84889	85338	85015~~.0~~
I13	~~98448.64~~	98429	94166~~.0~~	96003~~.0~~	~~96103.0~~	96850~~.0~~	~~98429.0~~	96003~~.0~~	96103~~.0~~	~~94260.0~~96834	~~94006.0~~97545	~~97050.0~~97082	97744	97050~~.0~~
#Best			1	1		4		2	2	5	4	6	11	5

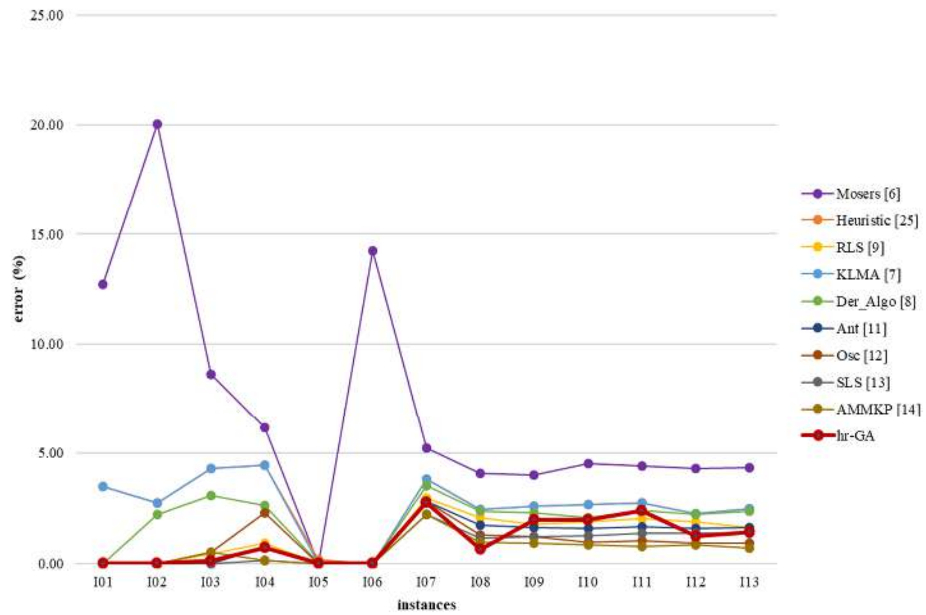

Figure 4. error comparison between heuristic approaches on all mm-KP instances

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In this research, we calculate the percentage error value for each instance by using the following formula:

Upper Bound $Error = \frac{best-optimum}{optimum} \; x \; 100\%$: Martello, S., & Toth, P. 1997. (5)

Mosers	: M. Moser, D. P. Jokanovi´c, and N. Shiratori. 1997.
Heuristic	: http://cermsem.univ-paris1.fr/pub/CERMSEM/hifi/MMKP/
HMS	: Hifi, Micrafy and Sbihi Algorithm by AbdelkaderSbihi, Michrafy Mustapha, MhandHifi, 2004.
RLS	: Reactive Local Search Algorithm by AbdelkaderSbihi, Michrafy Mustapha, MhandHifi, 2005.
MRLS	: Modified Reactive Local Search by AbdelkaderSbihi, Michrafy Mustapha, MhandHifi, 2007.
KLMA	: Khan, Li, Manning and Akbar Algortihm by S. Khan, K.F. Li, E.G. Manning, and MD. M. Akbar, 2002.
Der_Algo	: Derivied Algorithm. Hifi, M., Michrafy, M., dan Sbihi, A., 2005
GA1	: Genetic Algorithm by Khandaker Moinur Rahman, Syed Ishtiaque Ahmed, 2009.
sr-GA	: standard repairing-based GA
hr-GA	: hybrid repairing-based GA

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In this research, the relative The error values and the numbercomparisons of solutions optimally solved by GAs and other heuristics were computed. The percentage error value the heuristic methods for each instance is calculated by using the following formula:

$$Error = \frac{best - optimum}{\_} x\ 100\% \qquad ....(5)$$

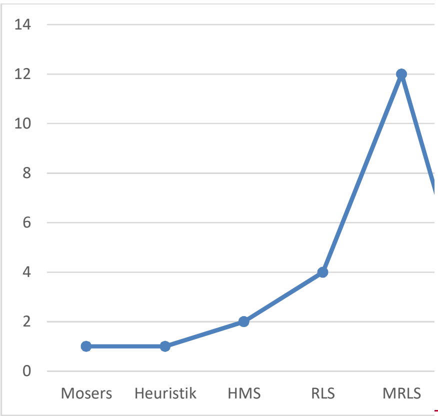
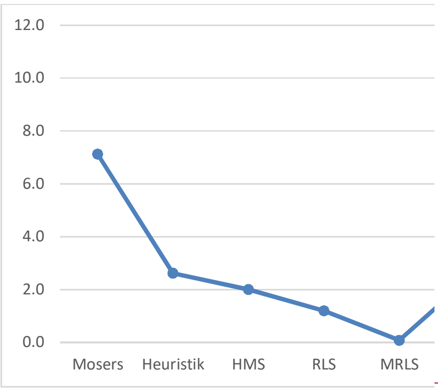


Figure 4 Number of instances solved optimally by methods



/optimal solution to the problem most of the time.

In this research, we also analyze the algorithm based on the average errors given by the methods for those 13 test problems. The computation indicates that hr-GA provides competitive solutions with the

Figures 4 and 5 show the comparison of the average errors of the methods and the number of instances. These results indicatetest problem are illustrated in Figure 4. It shows that hr-GA has the ability to can obtain good quality and reach more optimal solutions. However, in comparison to MRLS, the effectiveness of the GA needs to be improved.

average error equal to 1.02%, better than those obtained by Moser (7.13%), Heuristic (2.62%), RLS (1.2%), KLMA (2.6%), and Derived algorithm (1.93%), and the ant colony algorithm (1.03%). However, in comparison to the OSC algorithm (0.91%), SLS algorithm (0.77%), and AMMKP (0.61%), it still has a slightly larger average error. We illustrate the comparison of the average error for each method in the following Figure 5.

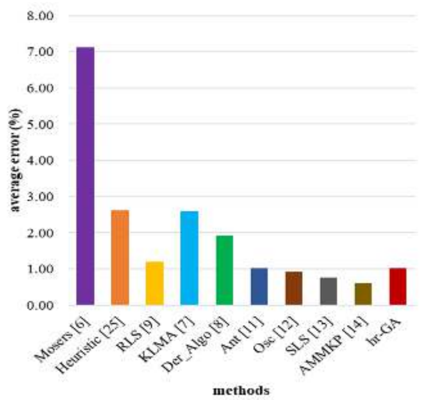


Figure 5 Comparative . Comparison of the average error oferrors between the heuristic methods

5. Conclusion

This paper analyzed three different Genetic Algorithm (GA) approaches forto solving mm-KP. The algorithms mainly differ in the handling method for the proposed methods adopt different strategies to handle infeasible chromosome. The researchchromosomes, namely penalty and repairing procedure. Those are also hybridized a new simple local search technique to the GA. The effectiveness and efficiency of the approaches are evaluated by intensiveimprove the solution quality. Several numerical experiments on a set of Benchmark instances taken from OR-Library. Furthermore, the proposed method was compared to have been conducted to evaluate the performance of the

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algorithms. The results show that repairing-based GA has better performance than penalty-based GA. Hybridizing GA with local search has also improved the solution quality immensely. The comparisons with other heuristic algorithms are also made based on the solution quality, the number of optimal solutions obtained, and average errors. ~~The results show~~It concludes that hr-GA ~~has the ability to reach optimal/near optimal solutions within reasonable computational time. It~~ is ~~also demonstrated that hybridizing GA with local search improves the solution quality immensely.~~ able to get competitive results with the other heuristics. These findings add to a growing body of literature on the applications of GA.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Mitsuo Gen gives the idea for the Algorithm; Admi Syarif and Dian Anggrainii designed the experiments; Dian Anggraini performed the experiments; Admi Syarif and Kurnia Muludi supervised the study, analyzed the results, verified the findings of the study, and wrote the paper.

Acknowledgments

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Comparing Various Genetic Algorithm Approaches for Multiple-choice Multi-dimensional Knapsack Problem (mm-KP)

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Abstract: One of the essential and well-known classes of combinatorial optimization problems commonly studies by researchers in the last five decades is called the Knapsack Problem (KP). Many variants of KP have been introduced for different real-world applications. Among them, the multiple-choice multi-dimensional Knapsack Problem (mm-KP) is the most complex model with an NP-hard problem. Several authors have reported the robustness of heuristics for mm-KP; irrespective of its advantages, no method currently has the ability to solve the problem optimally all time. This paper aims to determine the best GA strategy and evaluate the performance of several heuristic algorithms to solve mm-KP. We investigate the use of two techniques that are included in the GA approach. The first, two different strategies are adopted to handle infeasible chromosomes, namely penalty and repairing procedure. Second, we develop a new-simple local search to improve the quality of the solution found. Experimental studies on the 13 (thirteen) Benchmark instances are conducted to evaluate the effectiveness of the approach based on solutions quality, the number of the optimal solution reached, and average errors. The results showed that hr-GA tends to reach optimal/near-optimal solutions. Furthermore, the results from studies on heuristic algorithms also show that hr-GA is a promising approach, with local search used to immensely improve the quality.

Keywords: Repairing strategy, Local search, Heuristic method, Genetic algorithm, Knapsack problem.

1. Introduction

In 1950, Dantzig introduced the classical Knapsack Problem (KP), which is one of the famous combinatorial optimization problems. It represents the problem of selecting the subsets of the n items to maximize the corresponding profit, and the total weight does not exceed the Knapsack capacity. Practical applications of KP can be found in some of our daily life, such as the everyday diet program, an optimal investment plan, cargo loading, cutting stock, budget control, and financial management [1]. Different variants of KP are found in the literature, including, multiple-choice KP (mc-KP), multi-dimensional KP (md-KP), and multiple-choices multi-dimensional KP (mm-KP) [2]. Among them, mm-KP is the most complex belongs to the class of an NP-hard problem. It is considered as a variant of the md-KP where items are divided into groups, and precisely one item per group must be selected. The applications of mm-KP can be found in many real-life applications, including Chip Multiprocessor Run-time Resource Management [3], Global Routing of Wiring in Circuits [4], and Service Level Agreement [5].

The methods proposed in the literature to solve mm-KP can be grouped into two classes: exact and heuristic methods. Since mm-KP is an NP-hard problem, its search space exponentially grows as the problem size increases. Therefore, many researchers pay more attention to develop heuristic methods to

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solve mm-KP. Although the heuristics do not guarantee the finding of an optimal solution, those have been reported useful in determining optimal/near-optimal solutions for many hard optimization problems, including mm-KP.

To our knowledge, the first heuristic algorithm to solve mm-KP was reported by Moser et al. [6]. The authors introduced a Lagrangian Relaxation algorithm that was repeatedly permuting to reduce the infeasibility of solutions. A heuristic algorithm based on aggressive resource usage was proposed by Khan et al. [7]. This heuristic algorithm performs better than Moser's Algorithm. Then, Hifi presented several approaches to solve mm-KP. First, Hifi et al. proposed a heuristic approach with a guided-local search that used the principle based on trying several diversified solutions obtained after penalizing the costs of the objective function with penalties parameters [8]. Hifi et al. also developed an algorithm based on a reactive local search to try a diversification search and to escape local optima [9]. The authors reported that their methods are able to outperform Moser's and Khan's algorithms.

Later, Cherfi and Hifi presented column generation methods hybridized with branch-and-bound [10]. They reported that the approaches could obtain better solutions than former approaches on the benchmark instances. An ant colony algorithm approach to solve mm-KP was given by Iqbal et al. [11]. A heuristic method called oscillation (OSC Algorithm) was introduced by Htiouech et al. [12]. The authors used the constraint normalization method to improve the quality of solutions. Xia et al. developed another similar approach to the OSC algorithm, called Stochastic Local Search (SLS) [13]. The algorithm adopted a simple additive weighting scheme to adjust the weight (multiplier) on dimensions.

In one latest paper, Htiouech and Alzaidi proposed a heuristic algorithm called AMMKP [14]. The authors presented the way to decompose the mm -KP into many smaller sub-problems, and each subproblem then solved by an agent. The results show that the approach is able to solve several benchmark instances in the literature effectively.

Since Holland introduced it in 1975 [15], the Genetic Algorithm (GA) has been a prevalent heuristic method. Previous studies have shown the robustness of GA for various hard optimization problems, including the logistic problem [16] [17], scheduling problem [18], vehicle routing problem [19], and so on. For some specific cases, however, it often tends to provide local optimum and takes more time to reach optimal solutions. Therefore, it is crucial to carry out studies on designing an effective and efficient GA approach.

The most essential and influential component associated with the implementation of GA is the method used to represent the chromosome. For many optimization problems, it is difficult to express the chromosome in a way capable of fulfilling the constraint functions. This is because the generated chromosome in the population is either feasible or infeasible. Two strategies are usually adopted to overcome the infeasible situation, namely repairing and penalty [20]. Another critical issue in the applications of GA is associated with the strategies used to quit the local-optimal solution. The most common approach is to develop and hybridize GA with a local search technique [21].

This paper aims to determine the best GA strategy to solve mm-KP. To improve the quality of the solution, we developed a new simple local search and hybridized it into the GA loop. The approaches adopt both repairing and penalty strategy, namely as repairing-based (sr-GA), hybrid repairing-based GA (hr-GA), and hybrid penalty-based GA (hp-GA). Furthermore, some comparisons with other heuristic methods are also made based on the solution quality, average error, and the number of instances solved optimally.

To evaluate the approaches, we conducted some numerical experiments on set Benchmark test problems taken from OR-Library. The 13 (thirteen) widely studied instances are used to measure the performances of the algorithms. The experimental results show that hr-GA has the merit of high effectiveness and can obtain competitive results with the other heuristics.

We organize this paper into five sections. The second outlines the mathematical formulation of mm-KP. The brief designs of the proposed algorithms, including the chromosome representation, genetic operation, and local search technique, are presented in the third section. The numerical experiments and the comparison of results to other methods are described in the fourth section. Finally, conclusions are drawn in the last part.

2. Mathematical model and algorithm

Let

i	index of class
j	index of item
k	index of resource
R_k	resource constraint $R = R_1, R_2, R_3, \ldots, R_m$
r_{ij}^k	the need for the k^{th} resource for the j^{th} item in the i^{th} class

mm-KP aims to fill one item from each class of Knapsack in order to satisfy the resource capacity

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constraints and maximize the total profit values. Formally the mathematical formulation of mm-KP can be written as follows:

$$\max\ Z = \sum_{i=1}^{n} \sum_{j=1}^{r_i} x_{ij} v_{ij} \quad (1)$$

s.t.

$$\sum_{i=1}^{n} \sum_{j=1}^{r_i} r_{ij}^{k} x_{ij} \leq R_k, k \in \{1 \ldots\ldots, m\} \quad (2)$$

$$\sum_{j=1}^{r_i} x_{ij} = 1, i \in \{1, \ldots\ldots n\} \quad (3)$$

$$x_{ij} \in \{0,1\}, i \in \{1, \ldots\ldots n\}, j \in \{1, \ldots\ldots r_i\} \quad (4)$$

Here, the value of x_{ij} is either 1 or 0, which implies that item *j* in the *i*-th class is chosen, or not chosen. The v_{ij} represents the profit value of item *j* in the *i*-th class.

3. Design of the algorithms

3.1 Chromosome representation and evaluation

When implementing GA for a specific application, the first step is to determine a way to represent a possible solution to the problems. We have to generate some feasible chromosomes, which is as much as the desired population size. For this research, we represent chromosome by using a string, that its length is equal to the number of classes. For example, the dataset I01 comprises of five groups (*i*), five items (*j*), and five resources (*k*) in each class, with a resource constraint (R_k) of 25. The chromosome representation for this instance I01 can be illustrated in Fig. 1. The data for this instance (I01) is as follows:

In the above chromosome, the index represents the class, while the value item gene represents the item index *j* in each class *i*. From the chromosome, the selected items are 4, 5, 3, 2, and 4 in the 1st, 2nd, 3rd, 4th, and 5th class. The decoding mechanism is done by selecting one item for each category. The number of resource consumption (r_{ijk}) of each item is used to check for the resource constraint. Here, the total value of r_{ijk} cannot exceed the (R_k) amount of each class, as shown in Table 2.

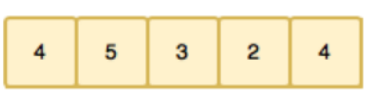

Figure. 1 Chromosome representation for instance I01

Table 1. Data for IO1 Instance

1					
7	1	3	1	1	6
17	1	4	9	9	3
25	4	3	9	8	2
35	4	5	8	0	6
36	6	8	3	0	7
2					
9	0	0	4	4	2
10	0	0	1	8	7
10	1	1	6	0	6
39	9	1	2	2	4
44	8	7	0	8	2
3					
15	2	0	5	5	5
19	2	3	2	6	2
20	3	1	6	4	7
44	6	7	5	6	9
50	9	5	9	2	2
4					
5	0	1	3	8	0
25	2	2	7	0	8
32	5	5	6	1	9
37	6	3	6	9	1
37	7	9	7	2	3
5					
24	4	0	7	0	2
30	4	8	9	0	0
32	5	2	7	2	0
43	5	5	9	5	2
44	9	2	2	2	3

Table 2. The decoding of the chromosome

	4	5	3	2	4
r_{ij1}	4	8	3	2	5
rij_2	5	7	1	2	5
r_{ij3}	8	0	6	7	9
r_{ij4}	0	8	4	0	5
r_{ij5}	6	2	7	8	1
R_k	23	25	21	19	25

3.2 Crossover and mutation

When implementing GA, two genetic operations are usually used to involve the new solution space, namely as crossover and mutation. The crossover operation is used to produce new offspring by recombining gen between selected parents. When choosing the crossover method, we have to consider the chromosome representation. There are several variants of the crossover methods introduced in the literature, such as one-point crossover, two-point crossover, PMX, WMX, etc.[8]. For this research, we

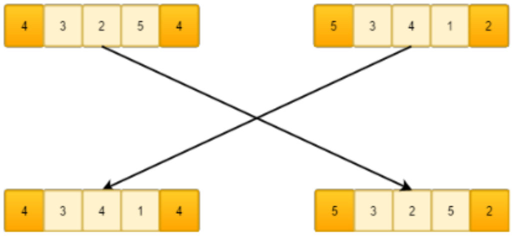

Figure. 2 The illustration of two-point crossover

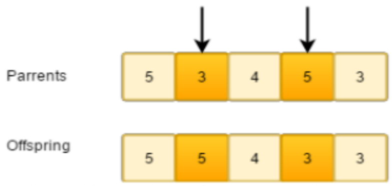

Figure. 3 The illustration of swap mutation operation

adopted the two-point crossover technique, as illustrated in Fig. 2 [22]. The following process explains the steps of the crossover operation.

Step 1: Choose two parents arbitrarily for crossover.
Step 2: Randomly determine two points
Step 3: Exchange the substring between these two points.

3.3 Selection strategy

The last stage of the GA process is the selection strategy to determine the chromosomes for the next generation. This stage adopted the elitist selection method. The *pop_size* best chromosomes (the highest fitness value) are chosen for the next generation.

3.4 Local search

Genetic algorithms (GA) function as a global search technique; however, it may often take a relatively long computational time to converge for a global optimum [24]. To solve this, many researchers suggested hybridizing GA with the local search technique. In this research, we developed a new and simple local search technique called Switching Local Search (SLS). It is done by first selecting a gene in the chromosome and changing its value randomly. The following Algorithm 1 illustrates the overall description of the proposed algorithms.

Algorithm 1: GAs for mm-KP
Input: data for the mm-KP test problem
Output: the best solution
Genetic Algorithm {
    Generate Initial population P(t);
    Evaluation Initial population P(t);
  Penalty strategy;
While (not STOPPING CONDITION)
    Crossover;
    Mutation;
    Evaluation;
    (Penalty/Repairing strategy);
    Selection;
    Local Search Best chromosome P(t);
    P = P(t+l);
  }
}

It is shown that two different strategies are used to handle an infeasible chromosome resulted in crossover and mutation operations. The first strategy includes a procedure to repair the infeasible chromosome. The second strategy applies the penalty value for the infeasible chromosome. As mm-KP is the maximization problem, the penalty value will decrease the objective value. Thus, it will reduce the opportunity of the chromosome to be selected for the next generation. The local search procedure was included in the GA loop and implemented to the best chromosome to improve the solution quality.

4. Experimental design and results

4.1 Experimental design

To evaluate the effectiveness of the algorithms, several experimental studies have been conducted on 13 (thirteen) different size Benchmark instances taken from OR-Library. The test problems were divided into 3 (three) groups according to the size; small size (I01-I06), medium (I07-I09), and large (I10-I13). The number of variables in these 13 test problems varies from 25 to 4000. The detail of the

Table 3. Details of the instances, where n denotes the number of classes, r_i is the number of items in each group, and m is the number of resources

No.	Test problem	Data				Parameter	
		N	r_i	***m***	R_k	***Pop _size***	***Max _gen***
1	I01	5	5	5	25	50	1000
2	I02	10	5	5	50	50	1500
3	I03	15	10	10	75	50	2000
4	I04	20	10	10	100	100	1000
5	I05	25	10	10	125	100	1500
6	I06	30	10	10	150	100	2000
7	I07	100	10	10	500	200	1000
8	I08	150	10	10	750	200	1500
9	I09	200	10	10	1000	250	2000
10	I10	250	10	10	1250	300	1000
11	I11	300	10	10	1500	300	1500
12	I12	350	10	10	1750	450	2000
13	I13	400	10	10	2000	500	2000

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Table 4. Performance of the GA approaches on all instances (SD: Standard Deviation)

Dataset	Optimum	sr-GA			hp-GA			hr-GA		
		Best	**Average**	**SD**	**Best**	**Average**	**SD**	**Best**	**Average**	**SD**
I01	173	**173**	173	0	**173**	170	2.9	**173**	173	0
I02	364	**364**	351	6.7	355	346.1	5.2	**364**	361	0.9
I03	1602	1536	1502.5	15.9	1556	1518	14.5	**1600**	1552.5	28.7
I04	3597	3433	3380.8	32.5	3488	3410	39.2	**3571**	3541.4	22
I05	3905.7	3900.4	3800.8	103	3905.7	3892	26.9	**3905.7**	3902	2.6
I06	4799.3	4787.2	4698.3	72.6	4799.3	4769.9	30.5	**4799.3**	4796	4.2
I07	24587	23071	22997.8	39.7	23717	23627	51.1	**23870**	23541.1	79.2
I08	36877	35536	34819.8	345.1	35547	32933	7764	**35626**	34932.4	90.2
I09	49167	47309	46237.6	540.7	47415	45946	748.1	**47370**	47338.1	43.8
I10	61437	58876	57826	568	59226	58898	245.1	**59228**	59056	40.3
I11	73773	70706	70557.3	142.1	70724	66620	1724.7	**71021**	70782.5	99.4
I12	86071	82089	89510.1	212	82305	77908	1195.6	**82627**	82342.8	104.5
I13	98429	94006	93478	279.2	94116	88429	1319.2	**94570**	94321.2	163

sr-GA: standard repairing-based GA (without local search)
hr-GA: hybrid repairing-based GA
hp-GA: hybrid penalty-based GA

test problems used for the experiments is shown in Table 3.

4.2 Results and discussion

A total of three GA approaches were developed, namely standard repairing GA (sr-GA), hybrid penalty-based (hp-GA), and hybridized penalty-based GA (hp-GA) by using Mathlab R2015b and run on PC Processor intel® Core™i5-3470S. For the experiments, we set the values of crossover probability and mutation probability as 0.4 and 0.2, respectively. Each algorithm is run 20 (twenty) times for each test problem.

Table 4 summarizes the overall results of the experiments, where the best and the average values represent the best and the average fitness value from the 20 (twenty) running times. Standard deviation (SD) is the distribution of statistical measures of the data distribution. Optimum is the best-obtained solution in the literature. The results highlight that repairing-based GA has better performance than penalty-based GA. Due to the difficulties in generating feasible chromosomes, the penalty strategy cannot give good results for all of the test problems. In addition, many offspring, which led to GA operations is also infeasible. It can be seen from these results that combining GA with the local search will improve the solution quality immensely. The overall results show that hr-GA has better performance to solve mm-KP all of the time.

To assess the merit and limit of the proposed approach, we compare the performance of the new hr-GA to other heuristic algorithms available in the following literature: Moser [6], Heuristic [25], Modified-Reactive-Local-Search (MRLS) [9], Khan-Li-Manning-Akbar Algorithm (KLMA) [7], Derived algorithm [8], Ant Colony Algorithm [11], OSC Algorithm [12], SLS Algorithm [13] and AMMKP algorithm [14].

Table 5 summarizes the comparison of the results obtained by the heuristic algorithms. Similarly, in this Table, we also indicate our achievements that have the values greater than or equal to the best-published results in bold. These results show that hr-GA tends to reach optimal/near-optimal solutions to the problem. It can obtain the number of solution that better than or equal to the best solution in 5 cases among 13 cases, which better or same as the results given by Moser (1 case), Heuristic (1 case), RLS (4 cases), KLMA (2 cases), Derived Algorithm (2 cases), Ant Colony algorithm (5 cases), OSC algorithm (4 cases), SLS algorithm (6 cases) and AMMKP (11 cases).

In this research, we calculate the percentage error value for each instance by using the following formula:

$$Error = \frac{best - optimum}{optimum} \; x \; 100\% \qquad (5)$$

The error comparisons of the heuristic methods for each test problem are illustrated in Figure 4. It shows that hr-GA can obtain good quality and reach optimal/optimal solution to the problem most of the time.

In this research, we also analyze the algorithm based on the average errors given by the methods for

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Table 5. Results of some heuristic methods on all mm-KP instances

Dataset	Optimum	Moser	Heuristic	RLS	KLMA	Der_ Algo	Ant	OSC	SLS	AMMKP	hr-GA
I01	173	151	167	**173**	167	**173**	**173**	**173**	**173**	**173**	**173**
I02	364	291	354	**364**	354	356	**364**	**364**	**364**	**364**	**364**
I03	1602	1464	1533	1595	1533	1553	**1602**	1594	**1602**	1594	1600
I04	3597	3375	3437	3564	3437	3502	3569	3514	**3592**	**3592**	3571
I05	3905.7	**3905.7**	3899.1	**3905.7**	**3905.7**	3905.2	**3905.7**	**3905.7**	**3905.7**	**3905.7**	**3905.7**
I06	4799.3	4115.2	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**	**4799.3**
I07	24857	23556	23912	24121	23912	23983	24159	24162	24311	**24310**	24170
I08	36877	35373	35979	36110	35979	36007	36240	36405	36463	36530	**36641**
I09	49167	47205	47901	48291	47901	48048	48367	48567	48580	**48711**	48191
I10	61437	58648	59811	60291	59811	60176	60475	60858	60661	**60911**	60228
I11	73773	70532	71760	72283	71760	72003	72558	73022	72778	**73200**	72003
I12	86071	82377	84141	84446	84141	84160	84707	85284	84889	**85338**	85015
I13	98429	94166	96003	96850	96003	96103	96834	97545	97082	**97744**	97050
#Best		**1**	**1**	**4**	**2**	**2**	**5**	**4**	**6**	**11**	**5**

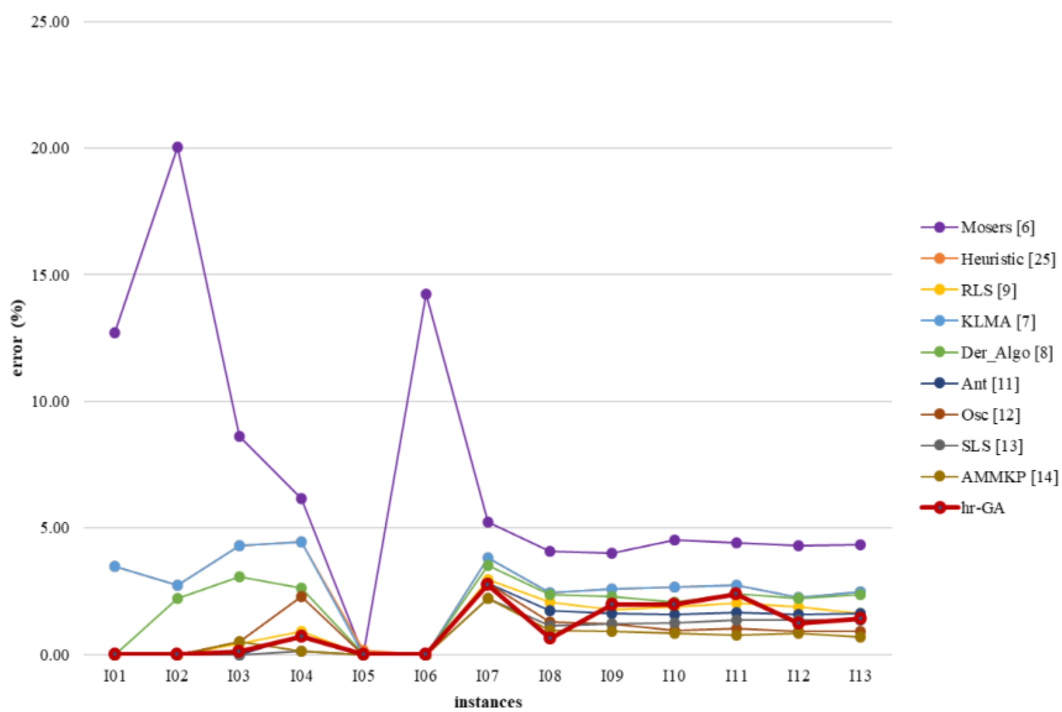

Figure 4. Error comparison between heuristic approaches on all mm-KP instances

those 13 test problems. The computation indicates that hr-GA provides competitive solutions with the average error equal to 1.02%, better than those obtained by Moser (7.13%), Heuristic (2.62%), RLS (1.2%), KLMA (2.6%), and Derived algorithm (1.93%), and the ant colony algorithm (1.03%). However, in comparison to the OSC algorithm (0.91%), SLS algorithm (0.77%), and AMMKP (0.61%), it still has a slightly larger average error. We illustrate the comparison of the average error for each method in the following Figure 5.

5. Conclusion

This paper analyzed three different GA approaches to solving mm-KP. The proposed methods adopt different strategies to handle

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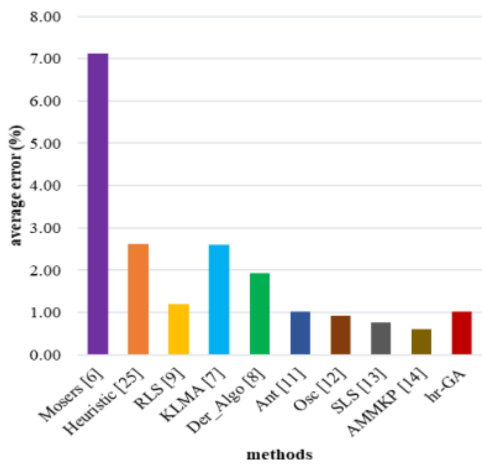

Figure 5. Comparison of the average errors between the heuristic methods

infeasible chromosomes, namely penalty and repairing procedure. Those are also hybridized a new simple local search technique to improve the solution quality. Several numerical experiments on a set of Benchmark instances taken from OR-Library have been conducted to evaluate the performance of the algorithms. The results show that repairing-based GA has better performance than penalty-based GA. Hybridizing GA with local search has also improved the solution quality immensely. The comparisons with other heuristic algorithms are also made based on the solution quality, the number of optimal solutions obtained, and average errors. It concludes that hr-GA is able to get competitive results with the other heuristics. These findings add to a growing body of literature on the applications of GA.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Mitsuo Gen gives the idea for the Algorithm; Admi Syarif and Dian Anggrainii designed the experiments; Dian Anggraini performed the experiments; Admi Syarif and Kurnia Muludi supervised the study, analyzed the results, verified the findings of the study, and wrote the paper.

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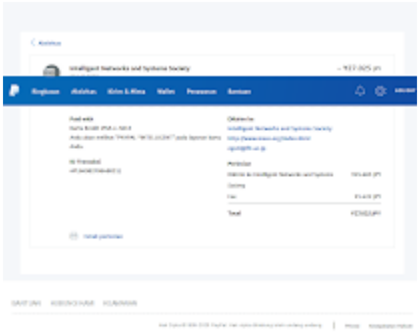

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Best regards,
IJIES Editors

From: ADMI SYARIF <admi.syarif@fmipa.unila.ac.id>
Sent: Wednesday, July 15, 2020 12:41 PM
To: ijies@inass.org; 江口 啓 <eguti@fit.ac.jp>
Subject: Revised Manuscript "(Paper ID: ijies3205)"

July 15, 2020

Dear Editor
First of all, we would like to express our great thanks for giving the opportunity to submit the revised version of our manuscript (Paper ID: Ijies3205), "Comparing Various Genetic Algorithm Approaches for Multiple-choice Multidimensional Knapsack Problem (mm-KP)" for publication in the International Journal of Intelligent Engineering and Systems. We appreciate your great comments and suggestion on our manuscript.

In this revised version, we have made significant improvements to our paper, following all reviewer comments and suggestions. We highlight the changes in the document. We have carefully checked and have proof-reading by a native-speaker on the earliest version of our paper. We also have similarity (Plagiarism) of the manuscript by using Turnitin (12 percent). We found that your comments and advice have improved and enriched the quality of the paper immensely.
Thank you very much for your assistance, and we are looking forward to hearing any information from you.

Sincerely Yours,

Admi Syarif, Ph.D. (Associate Professor)
Department of Computer Science
University of Lampung
Jl. S. Brodjonegoro No. 1, Bandar Lampung, 35145
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LAMPIRAN ACCEPTANCE LETTER

Intelligent Networks and Systems Society

Acceptance Letter

International Journal of Intelligent Engineering and Systems (IJIES)

July 22, 2020

Dear Admi Syarif,

Manuscript Title: Comparing Various Genetic Algorithm Approaches for Multiple-choice Multi-dimensional Knapsack Problem (mm-KP)

Author(s): Admi Syarif, Dian Anggraini, Kurnia Muludi, Wamiliana and Mitsuo Gen

Thank you for submitting your paper to the International Journal of Intelligent Engineering and Systems (IJIES). Based on double blind review process, we are pleased to inform you that our Review Committee has accepted your paper.

The paper will be included in the IJIES, which will be published with ISSN (ISSN: 2185-3118) in online on the website (http://www.inass.org/publications.html).
We are looking forward to your further contribution to our journal.

Kind regards

Prof. Dr. Kei EGUCHI
Editor-in-Chief, International Journal of Intelligent Engineering and Systems

Department of Information Electronics
Fukuoka Institute of Technology

Kei Eguchi

E-mail: ijies@inass.org

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LAMPIRAN TAGIHAN PEMBAYARAN PUBLIKASI ARTIKEL

Intelligent Networks and Systems Society

Official Receipt

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July 22, 2020

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IJIES formatting fee	1	25,603 JPY
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Title of a corresponding author (Prof./Assoc.Porf./Assis.Prof./Dr./Mr./Ms.)	Dr. Eng.
Full Name and Surname	ADMI SYARIF
Paper ID	#3205
Paper Title	Comparing Various Genetic Algorithm Approaches for Multiple-choice Multi-dimensional Knapsack Problem (mm-KP)
Authors	Admi Syarif, Dian Anggraini, Kurnia Muludi, Wamiliana and Mitsuo Gen
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3 messages

ADMI SYARIF <admi.syarif@fmipa.unila.ac.id> Thu, Jul 23, 2020 at 11:05 AM
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Dear Prof. Dr. Kei EGUCHI
Editor-in-Chief, International Journal of Intelligent Engineering and Systems

First of all, we would like to express our appreciation for your great work managing this high quality Journal. It is our great pleasure to inform you that we have received the acceptance letter and receipt of our (Paper ID: Ijies3205), "Comparing Various Genetic Algorithm Approaches for Multiple-choice Multidimensional Knapsack Problem (mm-KP)" for publication in the International Journal of Intelligent Engineering and Systems.
In this email, we send the signed copyright form for our paper. Thank you very much for your kind assistance, and we are looking forward to hearing any information from you.

Sincerely Yours,

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Dear author(s),

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In this email, we send the signed copyright form for our paper. Thank you very much for your kind assistance, and we are looking forward to hearing any information from you.

Sincerely Yours,

Admi Syarif, Ph.D. (Associate Professor)
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