

Adjusted Permutation Method for Multiple Attribute Decision Making with Pruning Solution Approach

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Abstract

Permutation method is one of the multi-criteria decision making techniques which can get the best order of the given alternatives to have the best benefits. This method solves the decision making problem by calculation the benefit of each possible permutation with N Factorial calculations for N alternatives. In this paper, we presented a new method for improving the classical permutation method. It works with pruning the possible permutation sequences of the alternatives to reach the best solution. Our method can solve the problem by less than $N(N-1)/2$ calculations. It tries to find the best order by comparing the effect of switching the places of two nearby alternatives in the permutation sequences.

Keywords: Multi-criteria Decision Making, Adjusted Permutation, Pruning.

Introduction

Multiple criteria decision making (MCDM) tries to help making the optimum decision from various alternatives with different and complex criteria. The MCDM problems can be divided into two categories: Multiple objective decisions making (MODM) and multiple attribute decision making (MADM). MODM focuses on a continuous decision space while MCDM focuses on problems with discrete decision spaces [1]. For each category there are very methods. For example, ELECTRE, AHP, SAW, TOPSIS, Permutation are presented methods for MADM. Each method has its benefits, limitations and performance. Therefore the decision maker have to choose the best method for his/her problem. In the other hands some methods which are suitable for some problems may be useful for other problems. Thus, it is possible to reach wrong solution with using unsuitable methods for the problem [2].

Standard Permutation Method

One of MCDM methods is the Permutation Method (PM) which calculates all available combinations of the given alternatives to reach the best order of them. Since this method has to calculate all of possible combinations of the alternatives to solve the problem, it could be a NP-Hard problem in large number of alternatives and criteria [3].

PM tries to calculate the benefit (R value) of each possible order of the alternatives and pick the highest one as the correct order. As there are $N!$ orders for N alternatives, the complexity of the PM is $N!$.

PM, calculates the R value of the current order of the alternatives as below:

Step1: assign matrix M for the current order of the alternatives

Step2: For each ranking, $(A_i \dots A_j)$, form the matrix of pair comparison in accordance with the decision Matrix. In this Matrix, R_{ij} is the total of the weights of attributes in which the alternative of i is higher or equal to j option.

Step 3: Calculating the score of Matrix whose quantity is equal to the difference of the total figures over the main diameter from the total figures below the main diameter.

The above steps should be repeated for each possible alternative orders and the order with the highest R value would be the correct answer of the problem.

Literature Review

One of the well-known and widely used methods for MADM is Simple Additive Weighting Method (SAW) which calculates the benefit of each alternative by summing the normalized value of each criteria.

Hwang and Yoon presented a method called "The technique for order preference by similarity to ideal solution" (TOPSIS) which calculates the best and worse optimum points as PIS and NIS by measuring all of the attributes. The best solution is the set of the attributes which has the minimum distance from the PIS and the maximum distance from the NIS [1].

The analytical hierarchy process (AHP) method, developed by Saaty uses decomposition, comparative judgment and synthesis of priorities to solve the decision making problem by hierarchy structure. AHP is also a powerful and well-known method in MADM [4].

The ELECTRE method which has more than 4 versions, originally presented in [5] in 1968 which tries to rank the alternatives. ELECTRE II, III and IV have improved the ranking method of first version.

Related Works

There are some previous works for adjusting the Permutation method. More of them use some meta heuristic methods to improve the permutation.

A particle swarm optimization algorithm (PSO) is presented in [6] to solve the

permutation flowshop sequencing problem with the objectives of minimizing make span and the total flowtime of jobs. The authors used a heuristic rule called the smallest position value and a variable neighborhood search method to solve the problems. The presented method can solve very large problems in a good processing time.

The authors of the [7] used a fast Tabu search algorithm with a back jump tracking method to reach the best order of the alternatives. Although the presented algorithm is a bit complex, but it can solve medium and large problems in an acceptable time.

Some meta-Heuristic methods such as PSO and Tabu Search (TS) have been developed for adjusting the permutation method in [2]. The authors have concluded that the proposed Tabu search method provides better results compared with PSO for large instances.

The author of [8] presented a method for ordering of feasible alternatives of solutions in terms of preferability technique. This method uses traditional permutation method for scoring each alternative order and then by gathering the impact of each alternative on the orders, the final order is presented as the solution.

An interactive permutation decision making method based on genetic algorithm is presented in [9] which uses the genetic methods to reach an initial solution of the problem and then tries to propose proper exchanges in each iteration by using the Interactive Simple Additive Weighting Method (ISAW).

Adjusting Permutation Method using Pruning Solution

As presented before, the PM has to calculate the R value for all possible orders of the alternatives (N Factorial cases for N alternatives) to solve the problem. Now, we are going to present a new method for adjusting permutation method using pruning the alternative orders. We call this new method "Pruning Permutation Method" (PPM). This method works with comparing the R value of some alternative orders and

deciding whether the similar types would result in better solution or not. The logic of the PPM is based on the effect of states of each alternative in the alternative orders.

Comparable Sequences

We call two alternative orders “comparable” if they differ just in one neighbor pair. For example $A1A2A3A4A5$ and $A1A3A2A4A5$ are comparable because they have 1 difference in places of $A2$ and $A3$ (which are neighbors and their places are switched). In the other hands, if places of more than 2 alternatives differ in the orders (For example $A1A2A3A4A5$ and $A1A3A2A5A4$), Or if two sequences have 1 difference in the places which are not neighbors (e.g. $A1A2A3A4A5$ and $A1A4A3A2A5$), they would be un-comparable. After defining the comparable orders, we can compare the R value of them and decide to use which sequences to reach the best solution. This will be discussed in the next part.

Pruning the Alternative Sequences

As presented in section 1.2, for calculating R value for each alternative order, a matrix is created and difference of the total figures over the main diameter from the total figures below the main diameter would present the R . therefore, to adjust the standard Permutation method, we should push the higher values to over the main diameter of the matrix and keep the lower ones in below.

The main idea of the PPM is examining the impact of each alternative in the orders and pushing the alternatives with higher impact on R value further in the orders. In this way, the difference of above and below of the main diameter in the matrix will be increased which will cause to higher R value. Therefore, we can prune the alternative orders in a way that only higher values remain at the end of the algorithm.

Because of the nature of the Permutation Method, the calculated R for each alternative order will differ from the others. Therefore, the correct position of each alternative will lead to the best solution of the problem. By examination of the positions of the alternatives and calculating the R value, we can decide the correct positions and prune the wrong ones.

For example, consider we have 4 alternatives named $A1$, $A2$, $A3$ and $A4$. Also consider $P1 = (A1A2A3A4)$ and $P2 = (A1A4A2A4)$ which $P1$ and $P2$ are comparative. If $R_{P1} > R_{P2}$ we can conclude that if $A2$ appear before $A3$, the result will be better than the case in which $A3$ appears before than $A2$. As a result, we can prune all of the alternative orders in which $A3$ appears before than $A2$ (this will cut the possible sequences to half!). This should be done for all possible comparative pairs of N alternatives. By this method, we can prune the alternative orders in a good rate. As there are $N(N-1)/2$ couple combinations for N alternatives, our proposed method will find the best alternative order after calculating the R value for $N(N-1)/2$ alternative orders.

The Algorithm of Pruning the Sequences

The purpose of PPM is pruning the alternative orders to reach the best solution. Therefore, we consider the first alternative order as the Temporary Best Solution (TBS) and start to compare it with other comparable alternative orders. If the second order increases the R value, we will consider it as TBS and follow its pattern and prune the reverse pattern, otherwise, we would compare the TBS with another comparable order until all of the other orders are pruned and just 1 order lefts (which is the best solution).

If the R value of two comparable orders is equal, we will mark them as “Recheck” to compare it in the next iterations in the future.

In this part, we are going to present the algorithm of pruning the sequences to restrict them and achieve the best solution:

- Generate all possible alternative orders ($P1 .. Pn$) and mark them “valid”.
- Set the TBS (Temporary Best Solution) to $P1$.
- While there are “valid” or “Recheck” comparable orders repeat level 3 to 5:
- Select a valid comparable order of TBS (Px) and calculate the R value for it.
- If $(R(Px) = R(P_{TBS}))$, mark P_x as “Recheck” and go to level 3.

- If $(R(P_x) > R(P_{TBS}))$, mark all of the orders with the same pattern of TBS as “invalid” and set $TBS=P_x$.

Else, mark all of the orders with the same pattern of P_x to “invalid”.

- If there are orders with “Recheck” mark, repeat levels 3-5 for them.
- Mark the remaining valid order as the solution.

Figure 1 shows the flowchart diagram of the PPM.

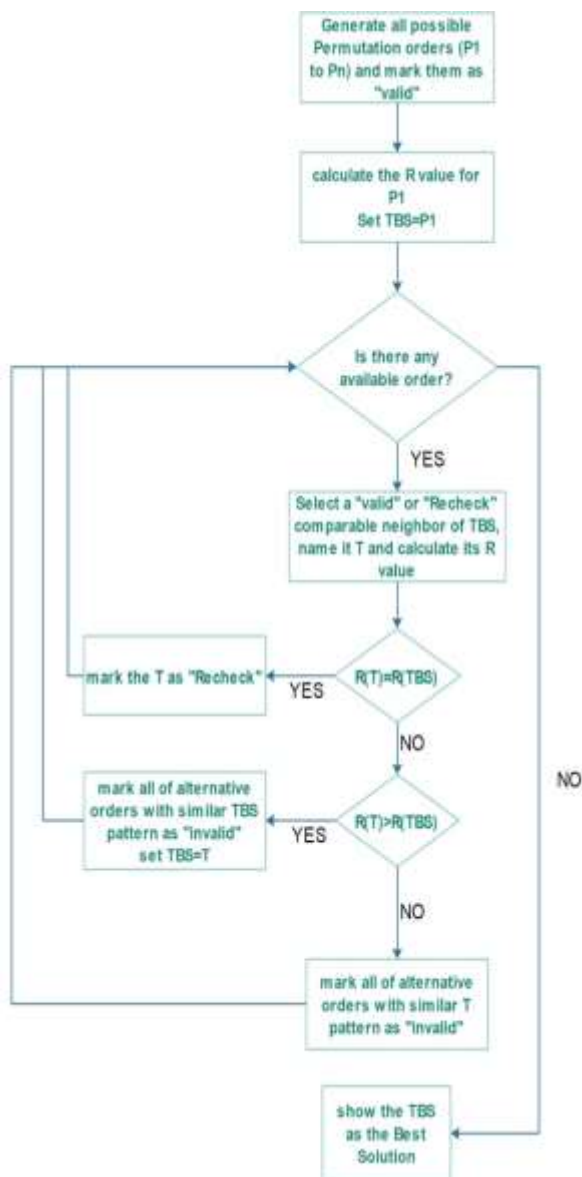


Figure 1: The PPM Algorithm

In the next sections we will explain the PPM algorithm with some examples.

Example 1

The first example is a simple problem with 3 alternatives and 3 criteria.

Table 1 shows the value of each alternative for problem criteria and the weights of them.

Table 1: Example 1 criteria

	1(-) W=0.3	2(+) W=0.4	3(+) W=0.3
A1	400	5	2000
A2	300	5	2420
A3	350	3	2400

This example will have 6 alternative orders which are shown in

Table 2:

Table 2: Permutation Sequences of Example 1

P1=A1A2A3	P3=A2A1A3	P5=A3A1A2
P2=A1A3A2	P4=A2A3A1	P6=A3A2A1

The PM have to calculate the R value 6 times for P1 to P6. Which are shown in Table 3:

Table 3: Calculated R values for Example 1

P1=A1A2A3=0.2	P3=A2A1A3=1.4	P5=A3A1A2=-1.4
P2=A1A3A2=-1.8	P4=A2A3A1=1.8	P6=A3A2A1=-0.2

After 6 calculations, the PM will reach to P4 as the best solution.

To solve this example with PPM, we should calculate $R(P1)$ and set the TBS to P1. One of P1's comparable orders should be examined and compared with it which we choose P2. By calculating the R value for P2 (which is -1.8) we find out that putting A3 before than A2 will worsen the result. So, we will prune all the alternative orders having A3 before than A2.

Table 4 shows the orders after first level of the PPM. The pruned cells are shown in strikethrough format.

Table 4: First Level of PPM on Example 1

P1=A1A2A3	P3=A2A1A3	P5=A3A1A2
P2=A1A3A2	P4=A2A3A1	P6=A3A2A1

In second iteration, we choose P4 as next comparable order of P1. by calculating the R for P4 (which is 1.8) it is obvious that the P4 is the best solution of the problem. (because there are no other valid orders and the R value of the P4 is the highest gained value). Table 5 shows the orders situation after second iteration of the PPM.

Table 5: Second Level of PPM on Example 1

P1=A1A2A3	P3=A2A1A3	P5=A3A1A2
P2=A1A3A2	P4=A2A3A1	P6=A3A2A1

Example 2:

The second example contains 4 alternatives with 6 criteria.

Table 6 shows the details and Table 7 shows the all of possible alternative sequences of first case study. Criteria 5 and 6 are qualitative that we have assign scores between 1 to 9 to them.

Table 6: Table of the Alternatives and criteria of example 2

Numbe r	1 (+)	2(+)	3(-)	4(-)	5(+)	6(+)
Weight	W=0.2	W=0.1	W=0.1	W=0.1	W=0.2	W=0.3
A1	2	1500	2000	5.5	5	9
A2	2.5	2700	1800	6.5	3	5
A3	1.8	2000	2100	4.5	7	7
A4	2.2	1800	2000	5	5	5

Table 7: all of possible permutations of example 2

P1 = (A1, A2, A3, A4)	P9 = (A2, A3, A1, A4)	P17 = (A3, A4, A1, A2)
P2 = (A1, A2, A4, A3)	P10 = (A2, A3, A4, A1)	P18 = (A3, A4, A2, A1)
P3 = (A1, A3, A2, A4)	P11 = (A2, A4, A1, A3)	P19 = (A4, A1, A2, A3)
P4 = (A1, A3, A4, A2)	P12 = (A2, A4, A3, A1)	P20 = (A4, A1, A3, A2)
P5 = (A1, A4, A2, A3)	P13 = (A3, A1, A2, A4)	P21 = (A4, A2, A1, A3)
P6 = (A1, A4, A3, A2)	P14 = (A3, A1, A4, A2)	P22 = (A4, A2, A3, A1)
P7 = (A2, A1, A3, A4)	P15 = (A3, A2, A1, A4)	P23 = (A4, A3, A1, A2)
P8 = (A2, A1, A4, A3)	P16 = (A3, A2, A4, A1)	P24 = (A4, A3, A2, A1)

The PPM will solve this problem with $4! = 24$ Calculations while our method will find the solution with only 6 calculations of R .

First of all we will calculate the $R(P1)$ and $R(P2)$ ($P2$ is comparable with $P1$, which they differ in the places of $A3$ and $A4$) which are (0.4) and (-0.6) respectively, then, by comparing these two sequences, we will notice that putting $A3$ after $A4$ will result in reduction of the R . so, we can prune all the alternative orders in which $A4$ is before than $A3$. By this, we will remove 12 sequences which are: $P2, P5, P6, P8, P11, P12, P19, P20, P21, P22, P23$, and $P24$. In this level, TBS is (0.4) and the TBS is: $A1, A2, A3$, and $A4$. Table 8 shows the orders of the problem after first iteration of the PPM.

Table 8: First level of PPM on example 2

P1 = (A1, A2, A3, A4)	P9 = (A2, A3, A1, A4)	P17 = (A3, A4, A1, A2)
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A3, A4)	A1, A4)	A1, A2)
~~P2 = (A1, A2, A4, A3)~~	~~P10 = (A2, A3, A4, A1)~~	~~P18 = (A3, A4, A2, A1)~~
P3 = (A1, A3, A2, A4)	~~P11 = (A2, A4, A1, A3)~~	~~P19 = (A4, A1, A2, A3)~~
P4 = (A1, A3, A4, A2)	P12 = (A2, A4, A3, A1)	~~P20 = (A4, A1, A3, A2)~~
~~P5 = (A1, A4, A2, A3)~~	P13 = (A3, A1, A2, A4)	~~P21 = (A4, A2, A1, A3)~~
~~P6 = (A1, A4, A3, A2)~~	P14 = (A3, A1, A4, A2)	~~P22 = (A4, A2, A3, A1)~~
P7 = (A2, A1, A3, A4)	P15 = (A3, A2, A1, A4)	~~P23 = (A4, A3, A1, A2)~~
~~P8 = (A2, A1, A4, A3)~~	P16 = (A3, A2, A4, A1)	~~P24 = (A4, A3, A2, A1)~~

In second iteration, we should compare TBS with one comparable order which could be $P7$. The R value of $P7$ is -0.4. Which tells us that putting $A2$ before $A1$ will makes the results worse. So we can prune all of the orders which have $A2$ before than $A1$. The pruned orders in this level are: $P7, P8, P9, P10, P11, P12, P15, P16, P18, P21, P22$, and $P24$. As it is observable, some of ignored sequences in this level have some similarities with level 1 (such as $P8, P11$). In this level we have ignored 6 new sequences. And have just 6 possible ones which should be examined.

Table 9 shows the results of this level.

Table 9: Second Level of PPM on Example 2

P1 = (A1, A2, A3, A4)	~~P9 = (A2, A3, A1, A4)~~	P17 = (A3, A4, A1, A2)
~~P2 = (A1, A2, A4, A3)~~	~~P10 = (A2, A3, A4, A1)~~	~~P18 = (A3, A4, A2, A1)~~
P3 = (A1, A3, A2, A4)	~~P11 = (A2, A4, A1, A3)~~	~~P19 = (A4, A1, A2, A3)~~
P4 = (A1, A3, A4, A2)	~~P12 = (A2, A4, A3, A1)~~	~~P20 = (A4, A1, A3, A2)~~
~~P5 = (A1, A4, A2, A3)~~	P13 = (A3, A1, A2, A4)	~~P21 = (A4, A2, A1, A3)~~
~~P6 = (A1, A4, A3, A2)~~	P14 = (A3, A1, A4, A2)	~~P22 = (A4, A2, A3, A1)~~
~~P7 = (A2, A1, A3, A4)~~	~~P15 = (A3, A2, A1, A4)~~	~~P23 = (A4, A3, A1, A2)~~
~~P8 = (A2, A1, A4, A3)~~	~~P16 = (A3, A2, A4, A1)~~	~~P24 = (A4, A3, A2, A1)~~

In level 3, we will examine the places of $A2$ and $A3$. To do this we should compare TBS with $P3$ ($A1, A3, A2, A4$). Since the $R(P3)$ is (1.2) which improves the result, we set the R_{max} to 1.2 and TBS to ($A1, A3, A2, A4$). Then we will prune all the sequences having $A2$ before $A3$.

Table 10: Third Level of PPM on Example 2

~~P1 = (A1, A2, A3, A4)~~	~~P9 = (A2, A3, A1, A4)~~	P17 = (A3, A4, A1, A2)
~~P2 = (A1, A2, A4, A3)~~	~~P10 = (A2, A3, A4, A1)~~	~~P18 = (A3, A4, A2, A1)~~
P3 = (A1, A3, A2, A4)	~~P11 = (A2, A4, A1, A3)~~	~~P19 = (A4, A1, A2, A3)~~
P4 = (A1, A3, A4, A2)	~~P12 = (A2, A4, A3, A1)~~	~~P20 = (A4, A1, A3, A2)~~
~~P5 = (A1, A4, A2, A3)~~	P13 = (A3, A1, A2, A4)	~~P21 = (A4, A2, A1, A3)~~
~~P6 = (A1, A4, A3, A2)~~	P14 = (A3, A1, A4, A2)	~~P22 = (A4, A2, A3, A1)~~

A3,A2)	A4,A2)	A3,A1)
P7 = (A2, A1,	P15 = (A3, A2,	P23 = (A4, A3,
A3,A4)	A1,A4)	A1,A2)
P8 = (A2, A1,	P16 = (A3, A2,	P24 = (A4, A3,
A4,A3)	A4,A1)	A2,A1)

In level 4, we will do the examination for A1 and A3. So, we should compare the TBS with P13 (A3, A1, A2, A4). By calculating R for P13, (1.2) will appear which does not differ from R_{max} . So we will mark the P13 as “Recheck”, ignore this level and will go to next one. It is necessary to say that we will compare A1 and A3 in the future after comparing A2 and A4.

Table 11: Forth Level of PPM on Example 2

P1 = (A1, A2,	P9 = (A2, A3,	P17 = (A3, A4,
A3,A4)	A1,A4)	A1,A2)
P2 = (A1, A2,	P10 = (A2, A3,	P18 = (A3, A4,
A4,A3)	A4,A1)	A2,A1)
P3 = (A1, A3,	P11 = (A2, A4,	P19 = (A4, A1,
A2,A4)	A1,A3)	A2,A3)
P4 = (A1, A3,	P12 = (A2, A4,	P20 = (A4, A1,
A4,A2)	A3,A1)	A3,A2)
P5 = (A1, A4,	P13 = (A3, A1,	P21 = (A4, A2,
A2,A3)	A2,A4)	A1,A3)
P6 = (A1, A4,	P14 = (A3, A1,	P22 = (A4, A2,
A3,A2)	A4,A2)	A3,A1)
P7 = (A2, A1,	P15 = (A3, A2,	P23 = (A4, A3,
A3,A4)	A1,A4)	A1,A2)
P8 = (A2, A1,	P16 = (A3, A2,	P24 = (A4, A3,
A4,A3)	A4,A1)	A2,A1)

In level 5, A2 and A4 will be examined. So we should calculate R(P14) which is (1.4). The results show that by putting A4 before A2, we have some improvements. So we will prune P3 and P13. And set R_{max} to 1.4 and TBS to (A3, A1, A4,A2).

Table 12: Fifth Level of PPM on Example 2

P1 = (A1, A2,	P9 = (A2, A3,	P17 = (A3, A4,
A3,A4)	A1,A4)	A1,A2)
P2 = (A1, A2,	P10 = (A2, A3,	P18 = (A3, A4,
A4,A3)	A4,A1)	A2,A1)
P3 = (A1, A3,	P11 = (A2, A4,	P19 = (A4, A1,
A2,A4)	A1,A3)	A2,A3)
P4 = (A1, A3,	P12 = (A2, A4,	P20 = (A4, A1,
A4,A2)	A3,A1)	A3,A2)
P5 = (A1, A4,	P13 = (A3, A1,	P21 = (A4, A2,
A2,A3)	A2,A4)	A1,A3)
P6 = (A1, A4,	P14 = (A3, A1,	P22 = (A4, A2,
A3,A2)	A4,A2)	A3,A1)
P7 = (A2, A1,	P15 = (A3, A2,	P23 = (A4, A3,
A3,A4)	A1,A4)	A1,A2)
P8 = (A2, A1,	P16 = (A3, A2,	P24 = (A4, A3,
A4,A3)	A4,A1)	A2,A1)

In level 6, we can compare A1 and A4 (P17) or A1 and A3 (P4). By calculating R (P17) which is (1.6), we will prune P4 and P14 which have A4 before than A1 and the method reaches to the best solution. If we choose to compare TBS with P4, no difference will happen and we have to compare TBS with P17 in next level.

As we discussed, our proposed method can prune the sequences in a very good rate which can reduce the complexity of the permutation method. In this case study, we have reached to the correct answer after calculating R for 6 or 7 alternative sequences which is much better than standard permutation method (which should calculate R for 24 sequences!)

Table 13: Sixth Level of PPM on Example 2

P1 = (A1, A2,	P9 = (A2, A3,	P17 = (A3, A4,
A3,A4)	A1,A4)	A1,A2)
P2 = (A1, A2,	P10 = (A2, A3,	P18 = (A3, A4,
A4,A3)	A4,A1)	A2,A1)
P3 = (A1, A3,	P11 = (A2, A4,	P19 = (A4, A1,
A2,A4)	A1,A3)	A2,A3)
P4 = (A1, A3,	P12 = (A2, A4,	P20 = (A4, A1,
A4,A2)	A3,A1)	A3,A2)
P5 = (A1, A4,	P13 = (A3, A1,	P21 = (A4, A2,
A2,A3)	A2,A4)	A1,A3)
P6 = (A1, A4,	P14 = (A3, A1,	P22 = (A4, A2,
A3,A2)	A4,A2)	A3,A1)
P7 = (A2, A1,	P15 = (A3, A2,	P23 = (A4, A3,
A3,A4)	A1,A4)	A1,A2)
P8 = (A2, A1,	P16 = (A3, A2,	P24 = (A4, A3,
A4,A3)	A4,A1)	A2,A1)

Performance Evaluation

In order to evaluate our new method's performance we developed PM and PPM with an event driven JAVA program. The evaluation results extracted from average of 10 replications per problem. We used a personal computer with a Core i7, 2.5 GHz processor and 8 GBs of RAM.

Problem 1

In this section, we use the PM and the PPM to solve the example 2 in section 2.5. Both methods, solved the problem in less than 1 millisecond. The iteration times for Standard Permutation and the PPM was 24 and 6 respectively.

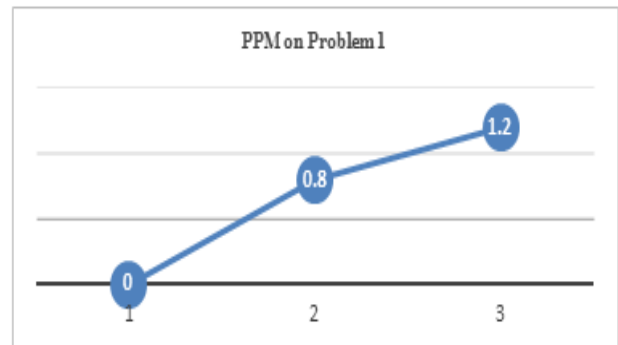


Figure 2: Process of solving problem 1

Figure 2 shows the solving process of problem 1.

Problem 2

To evaluate our method's performance, we have designed a problem with 10 alternatives and 5 criteria which is shown in Table 14. The negative criteria are shown with negative numbers.

Table 14: problem 1 criteria

	C1	C2	C3	C4	C5
A	22	-4.2	4	2	-21
B	25	-2.6	3	3	-20
C	24	-1.5	1	1	-27
D	15	-6.8	3	2	-59
E	35	-7.9	2	3	-67
F	18	-1.7	1	1	-34
G	12	-4.8	4	3	-26
H	20	-4.5	2	1	-34
I	23	-3.5	1	2	-65
J	22	-4.5	4	1	-52

After performing both PM and PPM on this problem, The best alternative order is "BAGECIJHFD" with the value of 18.1 for R .

The PM gives us the solution in 4.22 seconds while PPM do this in 2.1 seconds which is almost half of the PM. The PM calculates the R value for 10! Times (exactly 3628800 times) but the PPM solve the problem just with 32 replications of R calculations. Figure 3 shows the performance diagram of these two methods. And Figure 4 shows the process of solving this problem with PPM.

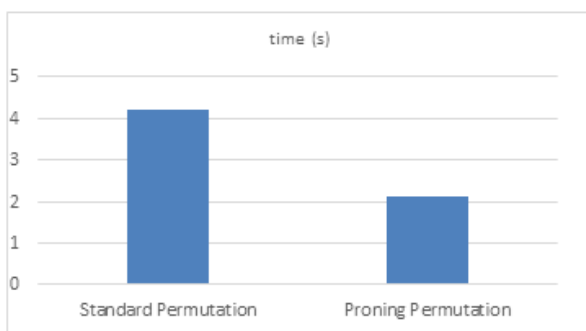


Figure 3: CPU time for problem 1

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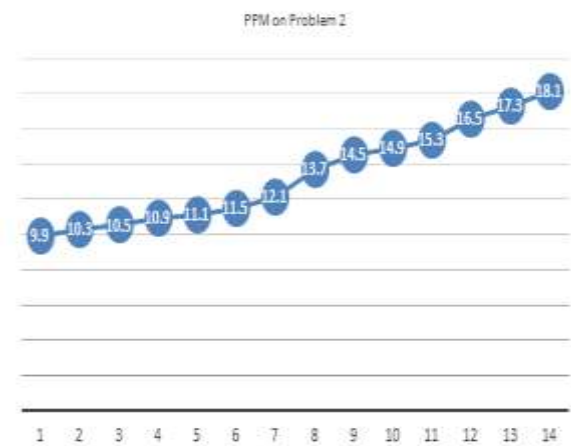


Figure 4: Process of solving problem 2

Conclusion

In this paper, we have proposed a new adjusted Permutation method with pruning approach named PPM which prunes the possible cases due to reduce the solving time and process.

The PPM tries to find the best place of each alternative in order to reach the best solution of the problem. Comparing the alternative's places in the alternative sequences and their impact on the R value of each alternative order is the main idea of the PPM.

Our performance evaluations show that the PPM could solve the complex problems in much less than the Standard Permutation method.

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