PANAMA

PRESCRIPTIVE SOLAR ANALYTICS & ADVANCED WORKFORCE MANAGEMENT

D3.3
Decision analysis and results

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Definition of Acronyms

PV	Photovoltaic
MCDA	Multi-Criteria Decision Analysis

Note: Mathematical symbols and terms are explained directly in the corresponding sections.

EXECUTIVE SUMMARY

Deliverable 3.3 titled “Decision analysis and results”, consists of two main sections. The first section describes the methodology of the MCDA tool, the criteria that are used as inputs, the weight’s assignment to each criterion as well as the output of the model. At the second part, the results of the model’s application on the project’s data are presented.

1 INTRODUCTION

MCDA is a decision-making tool, which is widely used for decision processes, since it has the ability to explicitly evaluate multiple conflict criteria. The criteria may refer to economic and technical constraints, risk factors and others. The main goal of MCDA analysis is not to find the optimal solution of a problem but to provide alternative solutions. In this way, the experts have the ability to think about the results of each decision and reject or accept the solution.

Several MCDA techniques have been proposed in literature. However, the most frequently used are [1]:

- ELimination Et Choix Traduisant la REalitè (ELECTRE)
- Multi-attribute utility theory (MAUT)
- Analytic Network Process (ANP)
- Measuring Attractiveness by a Categorical Based Evaluation (MACBETH)
- Analytic Hierarchy Process
- Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)
- Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

For the MCDA analysis the TOPSIS method is used. The selection of the specific technique is based on its simplicity and flexibility [2].

2 MCDA MODEL

The MCDA model is developed in order to address the problem of the optimal maintenance of faulty PV plants and it provides a ranking number for each alternative solution. The alternatives of the problem are all the feasible solutions that ensure the repairment of faulty systems (Figure 1). The main advantage of the deployment of MCDA model is its ability to take as inputs not only quantitative but also qualitative criteria for the estimation of the alternatives.

2.1 TOPSIS method

The solutions, provided by the TOPSIS method, refer to the available alternatives of PV maintenance procedures, considering several criteria. In our case, the alternatives are the different maintenance schedules that can be followed by the personnel, when one or more PV systems are under fault condition. The criteria on the other side, are the parameters that affect the cost of the maintenance plan. For the implementation of the method, two solutions should be estimated, namely the ideal and anti-ideal, respectively. Afterwards, the distances of every possible solution from the ideal and anti-ideal ones are calculated. Let A_i, $i = 1, 2, ..., m$ be the alternative solutions and z_j, $j = 1, 2, ..., n$ the criteria. The implementation of the TOPSIS method is based on the following steps:

Step#1. Build the decision matrix X with m alternative solutions and n criteria, with the intersection of each criterion and alternative given as x_{ij}:

$$X = \begin{matrix} & z_1 & z_2 & \cdots & z_n \\ A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ A_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix} \quad (1)$$

Step#2. Construct the $R = (r_{i,j})_{m \times n}$ matrix, which is the normalized X. Each $r_{i,j}$ element is denoted as:

$$r_{i,j} = \frac{x_{i,j}}{\sqrt{\sum_{k=1}^{m} x_{k,j}^2}}, \ i = 1,2,...,m, \ j = 1,2,...,n \quad (2)$$

Step#3. Construct the weighted normalized decision matrix V as:

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \quad (3)$$

where each element $v_{i,j}$ is denoted as:

$$v_{i,j} = w_{i,j} r_{i,j} \quad (4)$$

where, $w_{i,j}$ is the weight assigned to the connection of solution i (A_i) with criterion j (z_j). The weights are defined by the decision maker and influence the results of the decision process. This is the main characteristic of the TOPSIS method, since with this approach the user is able to change the weights in order to satisfy his/her needs.

Step#4. Calculate the ideal (V^+) and the inti-ideal (V^-) alternative as:

$$A^+ = \left\{ \left\langle \max v_{i,j} \middle| j \in J \right\rangle, \left\langle \min v_{i,j} \middle| j \in J' \right\rangle \right\} \quad (5)$$

$$A^- = \left\{ \left\langle \min v_{i,j} \middle| j \in J \right\rangle, \left\langle \max v_{i,j} \middle| j \in J' \right\rangle \right\} \quad (6)$$

where $J = \{1,2,...,n\}$ are the criteria having a positive impact to the solution and $J' = \{1,2,...,n\}$ are the criteria having a negative impact to the solution. Considering this, the ideal solution is the maximum value of the positive impact and the minimum of the negative impact, while the anti-ideal solution is the minimum value of positive and the maximum value of negative impacts.

Step#5. Calculate the distances between each alternative i and: a) the ideal-solution and b) the anti-deal solution.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{i,j} - A^+\right)^2}, \ i = 1,2,...,m \quad (7)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{i,j} - A^i\right)^2}, \ i = 1,2,...,m \quad (8)$$

Step#6. Calculate the relative proximity of each alterative i to the positive ideal solution.

$$RC_i = \frac{d^-}{d^- + d^+} \quad (9)$$

Step#7. Sort the alternatives i according to the values of RC_i.

2.2 Concept design

The actions that should be followed in order to restore the functionality of faulty PV systems, such as the selections of the route, the personnel team and the system's repairment order, is a decision-making problem. Based on this, the MCDA model provides a ranking number for each available alternative, as it is illustrated in Figure 1, considering several criteria. The criteria that should be considered for the alternative's selection are presented in Table 1 and are separated into quantitative and qualitative criteria.

Table 1. MCDA criteria.

Code	MCDA criteria	Quantitative	Qualitative
z1	Distance between the locations	✓	
z2	Time needed to travel between the locations	✓	
z3	Type of route to the PV site		✓
z4	History of fault occurrences on the PV site		✓
z5	System complexity		✓
z6	Level of personnel expertise		✓
z7	Urgency		✓
z8	Unavailability of personnel	✓	
z9	Working hours	✓	
z10	End of maintenance activities	✓	
z11	Transportation time of spare parts	✓	
z12	Forecasted PV power		✓
z13	Severity of fault		✓
z14	Severity of weather conditions		✓

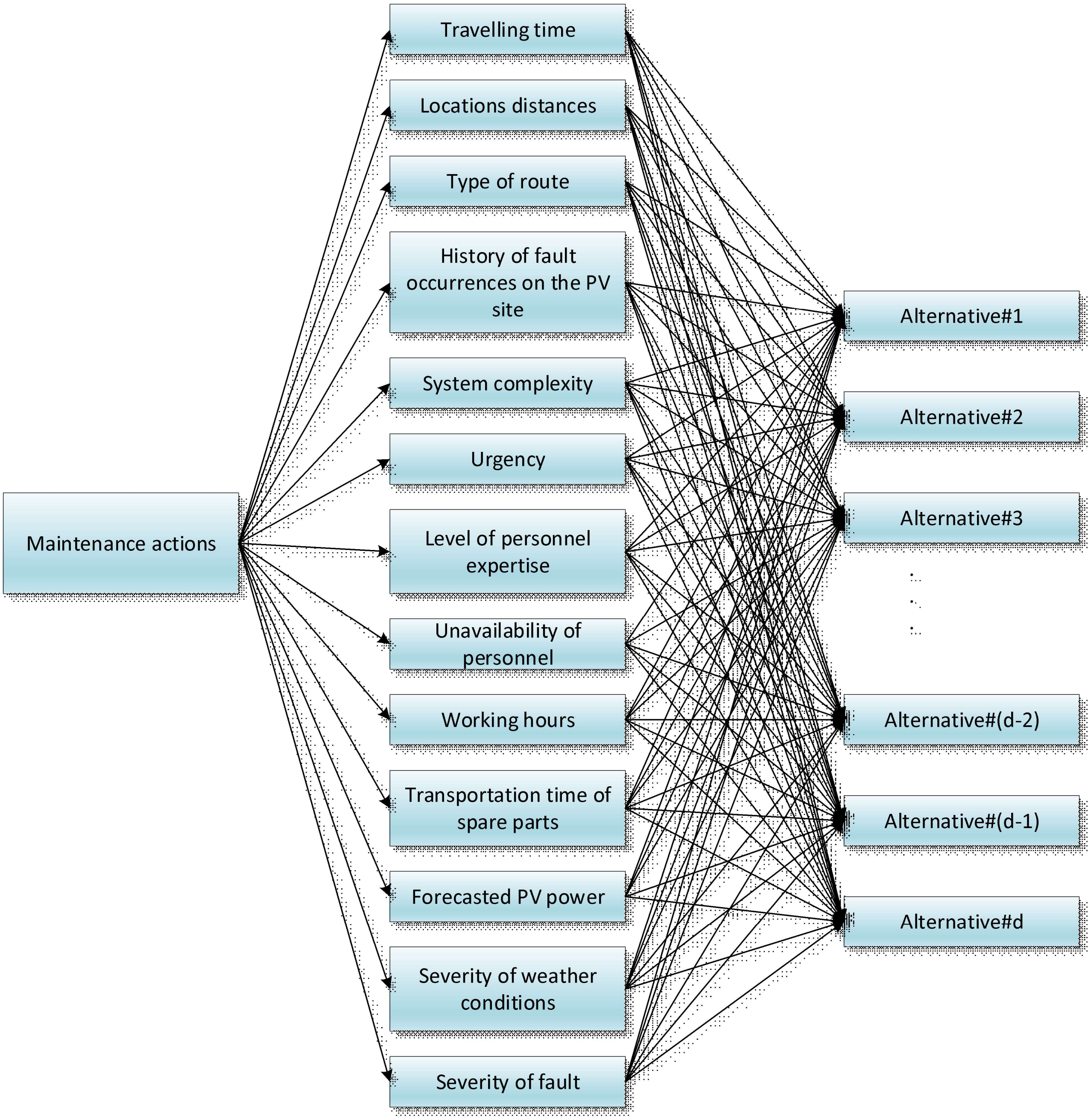

Figure 1. Alternative solutions considering the criteria of the problem

The criterion referring to the time needed to repair faulty PV systems depends on the type of fault. In Solar Bankability project an analysis was conducted based on failure records of 746 PV plants [3]. Table 2 presents the time required for the faults' repairment, based on the analysis' results. Since there are faults that require more than eight hours to be repaired, we separate the repairment time into maintenance intervals. For instance, for the repairment of a broken transformer, 48 hours are needed. In this case, we separate the fault into six sub-maintenance activities. Each activity is assumed to require eight hours for its completion. After the completion of the first activity, the second activity should be considered at the formulation of the alternatives. This is executed iteratively until all sub-maintenance activities are completed.

Table 2. Repairment time for each type of fault.

	Failures	Repair time (h)	Level of severity
Modules	Hotspot	2	Negligible
	Delamination	2	Negligible
	Glass breakage	2	Critical
	Soiling	0.01	Negligible
	Shading	0.01	Negligible
	Snail track	2	Negligible
	Cell cracks	2	Marginal
	Defective backsheet	2	Marginal
	Overheating junction box	2	Marginal
	PID = Pontetial Induced Degradation	2	Negligible
	Failure bypass diode and junction box	2	Marginal
	Corrosion in the junction box	2	Marginal
	EVA discoloration	0	Negligible
	Theft of modules	0.5	Critical
	Broken module	2	Critical
	Damage by snow	2	Critical
	Corrosion of cell connectors	2	Critical
	Improperly installed	2	Marginal
	Missing modules	2	Critical
Inverter	Fan failure and overheating	4	Critical
	Switch failure/damage	4	Critical
	Inverter firmware issue	4	Critical
	Polluted air filter – derating	4	Critical
	Inverter pollution	4	Critical
	Data entry broken	4	Critical
	Display off	4	Critical
	Wrong connection	4	Critical
	Burned supply cable and/or socket	4	Marginal
	Inverter wrongly sized	4	Marginal
	Wrong installation	4	Critical
Mo	Tracker failure	5	Marginal

	Not proper installation	48	Marginal
	Corrosion of module clamps	0.5	Marginal
	Disallignment caused by ground instability	48	Marginal
	Corrosion	24	Marginal
	Oil leakage	5	Marginal
Combined boxes	IP failure	24	Marginal
	Main switch open and does not reclose again	1	Critical
	Broken/Wrong general switch	1	Catastrophic
	Wrong wiring	24	Catastrophic
	General switch off	1	Catastrophic
	Wrong/Missing labeling	1	Marginal
	Incorrect installation	24	Catastrophic
	Overcurrent protection and correctly sized	4	Catastrophic
	Broken, missing or corroded cover	1	Critical
Cabling	UV aging	2	
	Theft cables	24	Catastrophic
	Broken cable ties	1	Catastrophic
	Wrong connection, isolation and/or settings	0.5	Catastrophic
	Broken/Burned connectors	0.5	Catastrophic
	Wrong/Absent cables connection		Catastrophic
	Wrong wiring	0.5	Catastrophic
	Cables undersized	48	Catastrophic
	Damage cable	1	Marginal
	Improper installation	1	Critical
	Conduit failure	2	Catastrophic
	Broken transformer	48	Catastrophic

Additionally, the categories of the qualitative criteria are presented in Table 3. Since several categories can lie under the same criterion, we have separated them into levels. Moreover, for the construction of the decision matrix (X) we have assigned a value for each level within a range [1, 9]. In criteria 1, 4 and 8 higher values of levels denote more favorable conditions. However, in criteria 2, 3, 5, 6 and 7 higher values of levels indicate that the faults should be repaired as soon as possible.

Table 3. Description of qualitative criteria.

No.	Criterion	Categories	Levels	Values in range 1-9
1	Type of route to the PV site	Earthen	Low	3
		Gravel	Medium	5
		Asphalt	High	8
2	History of fault occurrences on the PV site	Rarely	Low	3
		Often	Medium	5
		Most often	High	8
3	System complexity	Low	Low	3
		Medium	Medium	5
		High	High	8
4	Level of personnel expertise	Novice	Low	3
		Advanced beginner		
		Competent	Medium	5
		Proficient	High	8
		Expert		
5	Urgency	The system will be repaired two days after	High	3
		The system will be repaired the next day	Medium	5
		The system will be repaired within the current day	Low	8
6	Forecasted PV power	Average forecasted power < Average capacity	Low	3
		Average forecasted power = Average capacity	Medium	5
		Average forecasted power > Average capacity	High	8
7	Severity of fault	The level for each type of fault is presented in Table 3.	Negligible	2
			Marginal	4
			Critical	6
			Catastrophic	8
8	Severity of weather conditions	Sunny	Sunny	9
		Cloudy	Cloudy	7
		Rainy	Rainy	5

		Stormy	Stormy	3
		Snowy	Snowy	1

Table 4. Assignment of criteria values within range [1, 9].

Convert criterion values into ranged values

```
criterion_values = values of alternatives for the specific criterion
length = total alternatives

minimum = minimum value of criterion_values
maximum = maximum value of criterion_values
step = (minimum – maximum) / 9

bin = array(9x2)
ranged_criterion_values = array(length x 1)

bin[1][1] = minimum
bin[1][2] = maximum

for j=2 to 9:
    for i=1 to 2:
        if j<9 or i=1:
            bin[j][i] = bin[j-1][i] + step
             else:
            bin[j][i] = bin[j-1][i] + step + 1

for j=1 to length:
    for i=1 to 9:
        if i=1:
            if criterion_values[j] >= bin[i][1] and criterion_values[j] <= bin[i][2]:
                  ranged_criterion_values[j] = 9 – i
        else:
            if criterion_values[j] > bin[i][1] and criterion_values[j] <= bin[i][2]:
                    ranged_criterion_values[j] = 9 – i
```

Apart from the values of the qualitative criteria, for the construction of the decision matrix (X), the values of the quantitative criteria should be assigned to values within a range [1, 9] as well. This is achieved considering the minimum and the maximum arithmetical values of each criterion. Furthermore, for the assignment, we need to take into account if the criterion belongs to the benefit or cost criteria, since the highest value of the [1,9] range denotes the most favorable condition. For instance, the distance is a cost criterion, meaning that the minimum the distance between the PV site and the personnel's location is, the less fuels required and the quicker the personnel can travel to the system. So, in this case the minimum distance is assigned to the highest number of the range. The assignment has been accomplished based on the pseudocode, presented in Table 4.

Significant attention should be paid at the assignment of the working hours (z9). Considering the 8-hour work day, when the working hours do not exceed the 8 hours, then they are assigned to the value 9. However, when the working hours are more than 8, then the personnel have to work overtime, so values less than 9 are assigned. Finally, if the working hours per day exceed twelve, then they are assigned to the minimum value of the range, i.e., 1.

Apart from the working hours, we also need to examine if the maintenance activities that are assigned at each day have been completed by the end of the day. This is achieved with criterion z10 that refers to the end time of the maintenance activities assigned to the teams. The value of the criterion is set equal to zero, if the maintenance activities are completed within the same day, or one, if the maintenance activities are completed the next day.

After the construction of the decision matrix (X) the normalized decision matrix ($R = \left(r_{i,j}\right)_{m\times n}$) is estimated based on equation (2). However, for the next step, i.e., the calculation of the weighted normalized decision matrix V , the user should set a weight at each criterion. The weights' assignment is up to the knowledge of the expert and can be easily modified in order to fulfill the expectations of the problem. Yet, there is a constraint to be fulfilled at the assignment of the weights.

3 DATA DESCRIPTION

The model is tested on the projects' data which consists of six PV plants. Table 5 includes the system's information such as the system's location, the nominal capacity of the system and the recording frequency of the data. Additionally, since there are plants cited in the same location, a system code has been set for each pair of system-location. This assignment will be used for the formulation of the alternatives in TOPSIS method. Except from the timeseries of the produced PV power, we have measurements for meteorological conditions, i.e., solar irradiation, ambient temperature, as well as measurements of the panels' temperature.

Table 5. PV systems information.

PV system	Location	System-Location code	Nominal capacity (kW)	Recording frequency
Eragro_9	Guragac	*c*1	1155,00	15 min
Girayhan_3	Guragac	*c*2	1155,00	15 min
Eragro_8	Karasinir	*c*3	1149,00	15 min
Eragro_5	Secme	*c*4	1155,00	15 min
Eragro_7	Yenimescit	*c*5	1149,00	15 min
Eragro_6	Yenimescit	*c*6	1149,00	15 min

It is assumed that the maintenance agency is located in Karasinir. The location of the maintenance agency is assigned to "System-Location code" c7. The distances between the systems as well as the travelling time between the systems are presented in Table 6 and Table 7, respectively.

Table 6. Distances between the systems (km).

	*c*1	*c*2	*c*3	*c*4	*c*5	*c*6	*c*7
*c*1			6,3	52,4	26,4	26,4	6,3

c2			6,3	52,4	26,4	26,4	6,3
c3	6,3	6,3		52,2	27,3	27,3	
c4	52,4	52,4	52,2		46,2	46,2	52,2
c5	26,4	26,4	27,3	46,2			27,3
c6	26,4	26,4	27,3	46,2			27,3
c7	6,3	6,3		52,2	27,3	27,3	

Table 7. Travelling time between the locations (min).

	c1	***c2***	***c3***	***c4***	***c5***	***c6***	***c7***
c1			12	41	39	39	12
c2			12	41	39	39	12
c3	12	12		43	41	41	0
c4	41	41	43		40	40	43
c5	39	39	41	40			41
c6	39	39	41	40			41
c7	12	12	0	43	41	41	

4 RESULTS

The TOPSIS method has been applied to two different test cases, considering the project's data:

Test_case#1: The details of the tickets referring to Test_case#1 are presented in Table 8. Additionally, the weather severity, as well as the urgency of the repairment in terms of the repairment day are included in Table 9. The weights of all criteria have been set equal to 0.0833.

Test_case#2: In Test_case#2 we have to handle the same faults as Test_case#1 (Table 8). However, the weights of the criteria are not equal. The weights assigned to each criterion are illustrated in Table 10.

In all cases it is assumed that we have two teams (p1, p2) available to take over the maintenance activities. The level of expertise for teams p1 and p2 has been set to 'Competent' and 'Expert', respectively. Moreover, the model provides all the alternatives of the systems' repairmen for the current day, which is the day when the model is executed (d1), and for the next day (d2). The average forecasted PV power of the plants, which is included in Table 8, is the average PV power of the current and the next day and derives from the day ahead forecasting model, presented in Deliverable 3.2. Specifically, the forecasted PV power of the current day derives from the day-ahead model, by using as inputs historical data of PV power and meteorological conditions as well as meteorological forecasts of the day we attempt to predict. Since the model requires the solar irradiation and the ambient temperature forecasts as inputs, we assume that the measured data are predictions.

Table 8. Details of tickets for Test_case#1 and Test_case#2.

Faulty system	System-Location code	Time of fault detection	Type of fault	Severity of fault	Average forecasted power (kW)	Unavailability of spare parts	Time to repair (h)
Eragro_6	c6	15/05/2020 17:23	String tracker failure	Marginal	High	0	5
Eragro_7	c5	15/05/2020 17:23	Broken transformer	Catastrophic	High	0	48
Eragro_9	c1	15/05/2020 18:49	String tracker failure	Marginal	High	0	5
Girayhan_3	c2	15/05/2020 18:49	String tracker failure	Marginal	High	0	5
Eragro_6	c6	15/05/2020 19:18	Failure bypass diode and junction box	Negligible		0	2

Table 9. Criteria in terms of repairment day for Test_case#1 and Test_case#2.

Repairment day	Repairment day	System-Location code	Urgency	Weather severity
15/05/2020	d1	c5	Low	Sunny
	d1	c6	Low	Sunny
	d1	c1	Low	Cloudy
	d1	c2	Low	Cloudy
16/05/2020	d2	c5	Medium	Cloudy
	d2	c6	Medium	Cloudy
	d2	c1	Medium	Sunny
	d2	c2	Medium	Sunny

Table 10. Weight assignment per criterion.

MCDA criteria	Weight
Distance between the locations	**0,06**
Time needed to travel between the locations	0,06
Type of route to the PV site	0,06

History of fault occurrences on the PV site	0,06
Time needed to repair faulty PV plants	0,02
System complexity	0,07
Level of personnel expertise	0,09
Urgency	0,09
Availability of personnel	0,08
Working hours	0,08
Spare parts availability	0,08
Forecasted PV power	0,08
Severity of fault	0,09
Severity of weather conditions	0,08
total	**1**

Additionally, it is assumed that the type of route between the locations, which is one of the problem's criteria, is "Asphalt", as it is presented in Table 11.

Table 11. Type of road between the locations.

	***c*1**	***c*2**	***c*3**	***c*4**	***c*5**	***c*6**	***c*7**
***c*1**			Asphalt	Asphalt	Asphalt	Asphalt	Asphalt
***c*2**			Asphalt	Asphalt	Asphalt	Asphalt	Asphalt
***c*3**	Asphalt	Asphalt		Asphalt	Asphalt	Asphalt	Asphalt
***c*4**	Asphalt	Asphalt	Asphalt		Asphalt	Asphalt	Asphalt
***c*5**	Asphalt	Asphalt	Asphalt	Asphalt			Asphalt
***c*6**	Asphalt	Asphalt	Asphalt	Asphalt			Asphalt
***c*7**	Asphalt	Asphalt		Asphalt	Asphalt	Asphalt	

Furthermore, the history of fault occurrences at each plant, as well as the system's complexity are presented in Table 12.

Table 12. Systems' complexity and history of fault occurrences.

PV system	**System-Location code**	**History of fault occurrences**	**System complexity**
Eragro_9	*c*1	Medium	High
Girayhan_3	*c*2	Low	Medium
Eragro_8	*c*3	Low	Low
Eragro_5	*c*4	High	Medium

Eragro_7	*c*5	High	High
Eragro_6	*c*6	Medium	Medium

4.1 Test_case#1

At Test_case#1 five tickets open within the same day. Additionally, since the fault in c5 requires 48 hours to be repaired we separate the fault into six sub-maintenance activities. Considering the time of the faults' detection as well as the maintenance separation of system c6, the model is executed eight times as follows:

Iterration#1: two faults referring to the systems c5 and c6, cited in Yenimescit.

Iterration#2: two faults referring to the systems c1 and c2, cited in Guragac.

Iterration#3: one fault referring to system c6, cited in Yenimescit.

Itteration#4: the first sub-maintenance activity of c5 is completed and the second should be scheduled.

Iteration#5: the second sub-maintenance activity of c5 is completed and the third should be scheduled.

Iteration#6: the third sub-maintenance activity of c5 is completed and the fourth should be scheduled.

Iteration#7: the fourth sub-maintenance activity of c5 is completed and the fifth should be scheduled.

Iteration#8: the fifth sub-maintenance activity of c5 is completed and the sixth should be scheduled.

4.1.1 Iteration#1

At Iteration#1 we have to deal with the two faulty systems, i.e., *c*5 and *c*6. Considering that the time the tickets open both teams are located in *c*7, the alternatives of the problem are presented in Table 13.

Table 13. Alternatives at Test_Case#1 Iteration#1.

Alternative No.	Team	Day	Route
Al#1	*p*2 *p*2	*d*2 *d*2	*c*7->*c*5 *c*5->*c*6
Al#2	*p*2 *p*2	*d*2 *d*2	*c*7->*c*6 *c*6->*c*5
Al#3	*p*2 *p*2	*d*1 *d*2	*c*7->*c*5 *c*7->*c*6
Al#4	*p*2 *p*2	*d*1 *d*2	*c*7->*c*6 *c*7->*c*5
Al#5	*p*2 *p*2	*d*1 *d*1	*c*7->*c*5 *c*5->*c*6
Al#6	*p*2 *p*2	*d*1 *d*1	*c*7->*c*6 *c*6->*c*5
Al#7	*p*1	*d*2	*c*7->*c*5

	p2	*d2*	*c7->c6*
AI#8	*p1*	*d2*	*c7->c5*
	p2	*d1*	*c7->c6*
AI#9	*p1*	*d2*	*c7->c6*
	p2	*d2*	*c7->c5*
AI#10	*p1*	*d2*	*c7->c6*
	p2	*d1*	*c7->c5*
AI#11	*p1*	*d2*	*c7->c5*
	p1	*d2*	*c5->c6*
AI#12	*p1*	*d2*	*c7->c6*
	p1	*d2*	*c6->c5*
AI#13	*p1*	*d1*	*c7->c5*
	p2	*d2*	*c7->c6*
AI#14	*p1*	*d1*	*c7->c5*
	p2	*d1*	*c7->c6*
AI#15	*p1*	*d1*	*c7->c5*
	p1	*d2*	*c7->c6*
AI#16	*p1*	*d1*	*c7->c6*
	p2	*d2*	*c7->c5*
AI#17	*p1*	*d1*	*c7->c6*
	p2	*d1*	*c7->c5*
AI#18	*p1*	*d1*	*c7->c6*
	p1	*d2*	*c7->c5*
AI#19	*p1*	*d1*	*c7->c5*
	p1	*d1*	*c5->c6*
AI#20	*p1*	*d1*	*c7->c6*
	p1	d1	*c6->c5*

At table 14 the assignment of the criteria for the individual routes of each alternative are presented, while at Table 15 we have converted all the qualitative criteria with the values presented in Table 3. However, we need to consider that the alternatives consist of more than one routes. In this case, the final value of the alternatives' criteria is presented with the orange lines. The final value for each criterion is derived considering the quantity of each criterion, the teams that are selected for each repairment as well as the day of repairment. Specifically:

- For the distance (z1), the travelling time (z2), the unavailability of personnel (z8) and the unavailability of spare parts (z11) criteria, the summary is the sum of the individual routes, respectively.
- For the type of road to the PV site (z3), the history of fault occurrences (z4), the system complexity (z5), the level of personnel expertise (z6), the urgency (z7), the forecasted PV power (z12), the severity of fault (z13) and the severity of weather condition (z14) criteria, the summary derives as the average value of the individual maintenance activities, respectively.
- For the working hours of personnel (z9), the summary is the maximum working hours of the alternative. Additionally, in order to assess the individual maintenance activities, we take into account the day of repairment and the team which will repair

the system. For instance, at the Al#5, the repairment of both systems are assigned to the team *p*2 at day *d*1. Additionally, the team will visit first system *c*5 and then system *c*6. For the repairment of the first system the working hours are assessed to 8,683 hours, including the repairment time and the travelling time needed to get to the site. However, in order to assess the total working hours for the repairment of the second system, we take into account the working hours for the repairment of the first system (*c*5), the travelling time between locations *c*5 and *c*6 as well as the time required for the repairment of the second system (*c*6). So, the working hours for system *c*6 are assessed to 13,683.

- For the end of maintenance activities criterion (z10), the summary is equal to 1 if the repairment of the systems is completed within the same day, i.e., the day of the assignment, otherwise is equal to 0. In order to assess this, we take into account the time the model is executed as well as the travelling time and the time needed for the repairment of the systems. For instance, at Al#3, the repairment of system *c*5 is assigned to day *d*1, which is the day the model is executed. Considering that the model is executed at 17:23 and the repairment of the system requires 8,683 hours, the maintenance will end at the 26,067th hour of the day. Since the end of maintenance of *c*5 exceeds the 24 hours the repairment will be completed the next day (*d*2). Although the repairment of system *c*6 is scheduled for the next day and will be completed within the second day, the value of summary of the alternative's criterion will be set equal to 1 which derives from the first system. It should be mentioned that is more preferable all the maintenance activities to be completed the day they are scheduled.

The decision matrix is illustrated in Table 16. We have converted both qualitative and quantitative criteria within range [1, 9]. Furthermore, the normalized decision matrix ($R = \left(r_{i,j}\right)_{m \times n}$) is presented in Table 17, while the weighted normalized matrix (V) is illustrated in Table 18. Additionally, the ideal (A^{+}) and the anti-ideal (A^{-}) solutions of Iteration#1 are presented in Table 19. The distances between each alternative with the ideal-solution and the anti-deal solution, the relative closeness of each alterative to the ideal solution and the rank of the alternatives are presented in Table 20.

From the results it is obvious that the alternatives at which the maintenance activities are assigned to the same team are more favorable. This can be explained considering that the two systems are cited in the same location and the travelling distance between them is equal to zero. Additionally, if we compare Al#2 and Al#1, it is clear that the unavailability of the personnel (z8) affects the rank number of the alternatives, meaning that when the time of unavailability is lower the solution is more preferable.

Table 14. Criteria and alternatives at Test_case#1 Iteration#1.

	Team	Day	Route		z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	*p2*	*d2*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	*d2*	*c5->c6*	5	0	0	Asphalt	Medium	Medium	Expert	Medium	8,683	13,683	13,683	0	High	Marginal	Cloudy
AI#2	*p2*	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p2	*d2*	*c6->c5*	8	0	0	Asphalt	High	High	Expert	Medium	5,683	13,683	13,683	0	High	Catastrophic	Cloudy
AI#3	*p2*	*d1*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Low	0	8,683	26,067	0	High	Catastrophic	Sunny
	p2	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
AI#4	*p2*	*d1*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Low	0	5,683	23,067	0	High	Marginal	Sunny
	p2	*d2*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
AI#5	*p2*	*d1*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Low	0	8,683	26,067	0	High	Catastrophic	Sunny
	p2	*d1*	*c5->c6*	5	0	0	Asphalt	Medium	Medium	Expert	Low	8,683	13,683	31,067	0	High	Marginal	Sunny
AI#6	*p2*	*d1*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Low	0	5,683	23,067	0	High	Marginal	Sunny
	p2	*d1*	*c6->c5*	8	0	0	Asphalt	High	High	Expert	Low	5,683	13,683	31,067	0	High	Catastrophic	Sunny
AI#7	*p1*	*d2*	*c7->c5*	8	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Medium	8,683	5,683	5,683	0	High	Marginal	Cloudy
AI#8	*p1*	*d2*	*c7->c5*	8	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	*d1*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Low	0	5,683	23,067	0	High	Marginal	Sunny

AI#9	*p1*	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p2	*d2*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
AI#10	*p1*	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p2	*d1*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Low	0	8,683	26,067	0	High	Catastrophic	Sunny
AI#11	*p1*	*d2*	*c7->c5*	8	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p1	*d2*	*c5->c6*	5	0	0	Asphalt	Medium	Medium	Competent	Medium	8,683	13,683	13,683	0	High	Marginal	Cloudy
AI#12	*p1*	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p1	*d2*	*c6->c5*	8	0	0	Asphalt	High	High	Competent	Medium	5,683	13,683	13,683	0	High	Catastrophic	Cloudy
AI#13	*p1*	*d1*	*c7->c5*	8	27,3	41	Asphalt	High	High	Competent	Low	0	8,683	26,067	0	High	Catastrophic	Sunny
	p2	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
AI#14	*p1*	*d1*	*c7->c5*	8	27,3	41	Asphalt	High	High	Competent	Low	0	8,683	26,067	0	High	Catastrophic	Sunny
	p2	*d1*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Expert	Low	0	5,683	23,067	0	High	Marginal	Sunny
AI#15	*p1*	*d1*	*c7->c5*	8	27,3	41	Asphalt	High	High	Competent	Low	0	8,683	26,067	0	High	Catastrophic	Sunny
	p1	*d2*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
AI#16	*p1*	*d1*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Competent	Low	0	5,683	23,067	0	High	Marginal	Sunny
	p2	*d2*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	26,067	0	High	Catastrophic	Cloudy
AI#17	*p1*	*d1*	*c7->c6*	5	27,3	41	Asphalt	Medium	Medium	Competent	Low	0	5,683	23,067	0	High	Marginal	Sunny
	p2	*d1*	*c7->c5*	8	27,3	41	Asphalt	High	High	Expert	Low	0	8,683	26,067	0	High	Catastrophic	Sunny

AI#18	p1	d1	c7->c6	5	27,3	41	Asphalt	Medium	Medium	Competent	Low	0	5,683	23,067	0	High	Marginal	Sunny
	p1	d2	c7->c5	8	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
AI#19	p1	d1	c7->c5	8	27,3	41	Asphalt	High	High	Competent	Low	0	8,683	26,067	0	High	Catastrophic	Sunny
	p1	d1	c5->c6	5	0	0	Asphalt	Medium	Medium	Competent	Low	8,683	13,683	31,067	0	High	Marginal	Sunny
AI#20	p1	d1	c7->c6	5	27,3	41	Asphalt	Medium	Medium	Competent	Low	0	5,683	5,683	0	High	Marginal	Sunny
	p1	d1	c6->c5	8	0	0	Asphalt	High	High	Competent	Low	5,683	13,683	13,683	0	High	Catastrophic	Sunny

Table 15. Criteria and alternatives with numerical values at Test_case#1 Iteration#1.

	Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	*p2*	*d2*	*c7->c5*	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
	p2	*d2*	*c5->c6*	0	0	8	5	5	8	5	8,683	13,683	13,683	0	8	4	7
				27,3	41	8	6	6	8	5	8,683	13,683	0	0	8	6	7
AI#2	*p2*	*d2*	*c7->c6*	27,3	41	8	5	5	8	5	0	5,683	5,683	0	8	4	7
	p2	*d2*	*c6->c5*	0	0	8	8	8	8	5	5,683	13,683	13,683	0	8	8	7
				27,3	41	8	6	6	8	5	5,683	13,683	0	0	8	6	7
AI#3	*p2*	*d1*	*c7->c5*	27,3	41	8	8	8	8	2	0	8,683	26,067	0	8	8	9
	p2	*d2*	*c7->c6*	27,3	41	8	5	5	8	5	0	5,683	5,683	0	8	4	7
				54,6	82	8	6	6	8	6	0	8,683	1	0	8	6	8
AI#4	*p2*	*d1*	*c7->c6*	27,3	41	8	5	5	8	2	0	5,683	23,067	0	8	4	9
	p2	*d2*	*c7->c5*	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
				54,6	82	8	6	6	8	6	0	8,683	0	0	8	6	8
AI#5	*p2*	*d1*	*c7->c5*	27,3	41	8	8	8	8	2	0	8,683	26,067	0	8	8	9
	p2	*d1*	*c5->c6*	0	0	8	5	5	8	2	8,683	13,683	31,067	0	8	4	9
				27,3	41	8	6	6	8	8	8,683	13,683	1	0	8	6	9
AI#6	*p2*	*d1*	*c7->c6*	27,3	41	8	5	5	8	2	0	5,683	23,067	0	8	4	9
	p2	*d1*	*c6->c5*	0	0	8	8	8	8	2	5,683	13,683	31,067	0	8	8	9
				27,3	41	8	6	6	8	8	5,683	13,683	1	0	8	6	9
AI#7	*p1*	*d2*	*c7->c5*	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p2	*d2*	*c7->c6*	27,3	41	8	5	5	8	5	0	5,683	5,683	0	8	4	7
				54,6	82	8	6	6	6	5	0	8,683	0	0	8	6	7
AI#8	*p1*	*d2*	*c7->c5*	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p2	*d1*	*c7->c6*	27,3	41	8	5	5	8	2	0	5,683	23,067	0	8	4	9
				54,6	82	8	6	6	6	6	0	8,683	0	0	8	6	8
AI#9	*p1*	*d2*	*c7->c6*	27,3	41	8	5	5	5	5	0	5,683	5,683	0	8	4	7
	p2	*d2*	*c7->c5*	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
				54,6	82	8	6	6	6	5	0	8,683	0	0	8	6	7
AI#10	*p1*	*d2*	*c7->c6*	27,3	41	8	5	5	5	5	0	5,683	5,683	0	8	4	7
	p2	*d1*	*c7->c5*	27,3	41	8	8	8	8	2	0	8,683	26,067	0	8	8	9
				54,6	82	8	6	6	6	6	0	8,683	1	0	8	6	8

AI#11	*p1*	*d2*	*c7->c5*	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p1	*d2*	*c5->c6*	0	0	8	5	5	5	5	8,683	13,683	13,683	0	8	4	7
				27,3	41	8	6	6	5	5	8,683	13,683	0	0	8	6	7
AI#12	*p1*	*d2*	*c7->c6*	27,3	41	8	5	5	5	5	0	5,683	5,683	0	8	4	7
	p1	*d2*	*c6->c5*	0	0	8	8	8	5	5	5,683	13,683	13,683	0	8	8	7
				27,3	41	8	6	6	5	5	5,683	13,683	0	0	8	6	7
AI#13	*p1*	*d1*	*c7->c5*	27,3	41	8	8	8	5	2	0	8,683	26,067	0	8	8	9
	p2	*d2*	*c7->c6*	27,3	41	8	5	5	8	5	0	5,683	5,683	0	8	4	7
				54,6	82	8	6	6	6	6	0	8,683	1	0	8	6	8
AI#14	*p1*	*d1*	*c7->c5*	27,3	41	8	8	8	5	2	0	8,683	26,067	0	8	8	9
	p2	*d1*	*c7->c6*	27,3	41	8	5	5	8	2	0	5,683	23,067	0	8	4	9
				54,6	82	8	6	6	6	8	0	8,683	1	0	8	6	9
AI#15	*p1*	*d1*	*c7->c5*	27,3	41	8	8	8	5	2	0	8,683	26,067	0	8	8	9
	p1	*d2*	*c7->c6*	27,3	41	8	5	5	5	5	0	5,683	5,683	0	8	4	7
				54,6	82	8	6	6	5	6	0	8,683	1	0	8	6	8
AI#16	*p1*	*d1*	*c7->c6*	27,3	41	8	5	5	5	2	0	5,683	23,067	0	8	4	9
	p2	*d2*	*c7->c5*	27,3	41	8	8	8	8	5	0	8,683	26,067	0	8	8	7
				54,6	82	8	6	6	6	6	0	8,683	0	0	8	6	8
AI#17	*p1*	*d1*	*c7->c6*	27,3	41	8	5	5	5	2	0	5,683	23,067	0	8	4	9
	p2	*d1*	*c7->c5*	27,3	41	8	8	8	8	2	0	8,683	26,067	0	8	8	9
				54,6	82	8	6	6	6	8	0	8,683	1	0	8	6	9
AI#18	*p1*	*d1*	*c7->c6*	27,3	41	8	5	5	5	2	0	5,683	23,067	0	8	4	9
	p1	*d2*	*c7->c5*	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
				54,6	82	8	6	6	5	6	0	8,683	0	0	8	6	8
AI#19	*p1*	*d1*	*c7->c5*	27,3	41	8	8	8	5	2	0	8,683	26,067	0	8	8	9
	p1	*d1*	*c5->c6*	0	0	8	5	5	5	2	8,683	13,683	31,067	0	8	4	9
				27,3	41	8	6	6	5	8	8,683	13,683	1	0	8	6	9
AI#20	*p1*	*d1*	*c7->c6*	27,3	41	8	5	5	5	2	0	5,683	23,067	0	8	4	9
	p1	d1	*c6->c5*	0	0	8	8	8	5	2	5,683	13,683	31,067	0	8	8	9
				27,3	41	8	6	6	5	8	5,683	13,683	1	0	8	6	9

Table 16. Decision matrix (X) at Test_case#1 Iteration#1.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	9	9	8	6	6	8	5	1	1	9	9	3	6	7
AI#2	9	9	8	6	6	8	5	4	1	9	9	3	6	7
AI#3	1	1	8	6	6	8	6	9	9	1	9	3	6	8
AI#4	1	1	8	6	6	8	6	9	9	9	9	3	6	8
AI#5	9	9	8	6	6	8	8	1	1	1	9	3	6	9
AI#6	9	9	8	6	6	8	8	4	1	1	9	3	6	9
AI#7	1	1	8	6	6	6	5	9	9	9	9	3	6	7
AI#8	1	1	8	6	6	6	6	9	9	9	9	3	6	8
AI#9	1	1	8	6	6	6	5	9	9	9	9	3	6	7
AI#10	1	1	8	6	6	6	6	9	9	1	9	3	6	8
AI#11	9	9	8	6	6	5	5	1	1	9	9	3	6	7
AI#12	9	9	8	6	6	5	5	4	1	9	9	3	6	7
AI#13	1	1	8	6	6	6	6	9	9	1	9	3	6	8
AI#14	1	1	8	6	6	6	8	9	9	1	9	3	6	9
AI#15	1	1	8	6	6	5	6	9	9	1	9	3	6	8
AI#16	1	1	8	6	6	6	6	9	9	9	9	3	6	8
AI#17	1	1	8	6	6	6	8	9	9	1	9	3	6	9
AI#18	1	1	8	6	6	5	6	9	9	9	9	3	6	8
AI#19	9	9	8	6	6	5	8	1	1	1	9	3	6	9
AI#20	9	9	8	6	6	5	8	4	1	1	9	3	6	9

Table 17. Normalized decision matrix (R) at Test_case#1 Iteration#1.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,350	0,350	0,224	0,224	0,224	0,279	0,174	0,031	0,032	0,314	0,224	0,224	0,224	0,195
AI#2	0,350	0,350	0,224	0,224	0,224	0,279	0,174	0,124	0,032	0,314	0,224	0,224	0,224	0,195
AI#3	0,039	0,039	0,224	0,224	0,224	0,279	0,209	0,279	0,287	0,035	0,224	0,224	0,224	0,223
AI#4	0,039	0,039	0,224	0,224	0,224	0,279	0,209	0,279	0,287	0,314	0,224	0,224	0,224	0,223
AI#5	0,350	0,350	0,224	0,224	0,224	0,279	0,279	0,031	0,032	0,035	0,224	0,224	0,224	0,250
AI#6	0,350	0,350	0,224	0,224	0,224	0,279	0,279	0,124	0,032	0,035	0,224	0,224	0,224	0,250
AI#7	0,039	0,039	0,224	0,224	0,224	0,209	0,174	0,279	0,287	0,314	0,224	0,224	0,224	0,195
AI#8	0,039	0,039	0,224	0,224	0,224	0,209	0,209	0,279	0,287	0,314	0,224	0,224	0,224	0,223
AI#9	0,039	0,039	0,224	0,224	0,224	0,209	0,174	0,279	0,287	0,314	0,224	0,224	0,224	0,195
AI#10	0,039	0,039	0,224	0,224	0,224	0,209	0,209	0,279	0,287	0,035	0,224	0,224	0,224	0,223
AI#11	0,350	0,350	0,224	0,224	0,224	0,174	0,174	0,031	0,032	0,314	0,224	0,224	0,224	0,195
AI#12	0,350	0,350	0,224	0,224	0,224	0,174	0,174	0,124	0,032	0,314	0,224	0,224	0,224	0,195
AI#13	0,039	0,039	0,224	0,224	0,224	0,209	0,209	0,279	0,287	0,035	0,224	0,224	0,224	0,223
AI#14	0,039	0,039	0,224	0,224	0,224	0,209	0,279	0,279	0,287	0,035	0,224	0,224	0,224	0,250

Al#15	0,039	0,039	0,224	0,224	0,224	0,174	0,209	0,279	0,287	0,035	0,224	0,224	0,224	0,223
Al#16	0,039	0,039	0,224	0,224	0,224	0,209	0,209	0,279	0,287	0,314	0,224	0,224	0,224	0,223
Al#17	0,039	0,039	0,224	0,224	0,224	0,209	0,279	0,279	0,287	0,035	0,224	0,224	0,224	0,250
Al#18	0,039	0,039	0,224	0,224	0,224	0,174	0,209	0,279	0,287	0,314	0,224	0,224	0,224	0,223
Al#19	0,350	0,350	0,224	0,224	0,224	0,174	0,279	0,031	0,032	0,035	0,224	0,224	0,224	0,250
Al#20	0,350	0,350	0,224	0,224	0,224	0,174	0,279	0,124	0,032	0,035	0,224	0,224	0,224	0,250

Table 18. Weighted matrix (V) at Test_case#1 Iteration#1.

	z1	z2	z3	z4	z6	z7	z8	z9	z10	z11	z12	z13	z14	z15
Al#1	0,025	0,025	0,016	0,016	0,016	0,020	0,012	0,002	0,002	0,022	0,016	0,016	0,016	0,014
Al#2	0,025	0,025	0,016	0,016	0,016	0,020	0,012	0,009	0,002	0,022	0,016	0,016	0,016	0,014
Al#3	0,003	0,003	0,016	0,016	0,016	0,020	0,015	0,020	0,021	0,002	0,016	0,016	0,016	0,016
Al#4	0,003	0,003	0,016	0,016	0,016	0,020	0,015	0,020	0,021	0,022	0,016	0,016	0,016	0,016
Al#5	0,025	0,025	0,016	0,016	0,016	0,020	0,020	0,002	0,002	0,002	0,016	0,016	0,016	0,018
Al#6	0,025	0,025	0,016	0,016	0,016	0,020	0,020	0,009	0,002	0,002	0,016	0,016	0,016	0,018
Al#7	0,003	0,003	0,016	0,016	0,016	0,015	0,012	0,020	0,021	0,022	0,016	0,016	0,016	0,014
Al#8	0,003	0,003	0,016	0,016	0,016	0,015	0,015	0,020	0,021	0,022	0,016	0,016	0,016	0,016
Al#9	0,003	0,003	0,016	0,016	0,016	0,015	0,012	0,020	0,021	0,022	0,016	0,016	0,016	0,014
Al#10	0,003	0,003	0,016	0,016	0,016	0,015	0,015	0,020	0,021	0,002	0,016	0,016	0,016	0,016
Al#11	0,025	0,025	0,016	0,016	0,016	0,012	0,012	0,002	0,002	0,022	0,016	0,016	0,016	0,014
Al#12	0,025	0,025	0,016	0,016	0,016	0,012	0,012	0,009	0,002	0,022	0,016	0,016	0,016	0,014
Al#13	0,003	0,003	0,016	0,016	0,016	0,015	0,015	0,020	0,021	0,002	0,016	0,016	0,016	0,016
Al#14	0,003	0,003	0,016	0,016	0,016	0,015	0,020	0,020	0,021	0,002	0,016	0,016	0,016	0,018
Al#15	0,003	0,003	0,016	0,016	0,016	0,012	0,015	0,020	0,021	0,002	0,016	0,016	0,016	0,016
Al#16	0,003	0,003	0,016	0,016	0,016	0,015	0,015	0,020	0,021	0,022	0,016	0,016	0,016	0,016
Al#17	0,003	0,003	0,016	0,016	0,016	0,015	0,020	0,020	0,021	0,002	0,016	0,016	0,016	0,018
Al#18	0,003	0,003	0,016	0,016	0,016	0,012	0,015	0,020	0,021	0,022	0,016	0,016	0,016	0,016
Al#19	0,025	0,025	0,016	0,016	0,016	0,012	0,020	0,002	0,002	0,002	0,016	0,016	0,016	0,018
Al#20	0,025	0,025	0,016	0,016	0,016	0,012	0,020	0,009	0,002	0,002	0,016	0,016	0,016	0,018

Table 19. Ideal (A^{+}) and the anti-ideal (A^{-}) solutions at Test_case#1 Iteration#1.

Criterion code	A^{+}	A^{-}
z1	0,0250	0,0028
z2	0,0250	0,0028
z3	0,0160	0,0160
z4	0,0160	0,0160
z5	0,0160	0,0160
z6	0,0199	0,0125
z7	0,0199	0,0125
z8	0,0199	0,0022
z8	0,0205	0,0023
z10	0,0224	0,0025

z11	0,0160	0,0160
z12	0,0160	0,0160
z13	0,0160	0,0160
z14	0,0179	0,0139

Table 20. Ranking of maintenance plans at Test_case#1 Iteration#1.

Alternatives Code	d^+	d^-	RC	Rank
Al#1	0,0268	0,0380	0,5863	3
Al#2	0,0230	0,0386	0,6268	1
Al#3	0,0376	0,0267	0,4151	17
Al#4	0,0319	0,0333	0,5109	7
Al#5	0,0323	0,0334	0,5083	8
Al#6	0,0292	0,0341	0,5383	5
Al#7	0,0330	0,0324	0,4960	12
Al#8	0,0323	0,0326	0,5022	9
Al#9	0,0330	0,0324	0,4960	12
Al#10	0,0380	0,0258	0,4042	18
Al#11	0,0278	0,0373	0,5724	4
Al#12	0,0242	0,0378	0,6104	2
Al#13	0,0380	0,0258	0,4042	18
Al#14	0,0376	0,0269	0,4174	15
Al#15	0,0384	0,0256	0,4005	20
Al#16	0,0323	0,0326	0,5022	9
Al#17	0,0376	0,0269	0,4174	15
Al#18	0,0328	0,0325	0,4978	11
Al#19	0,0332	0,0326	0,4954	14
Al#20	0,0302	0,0332	0,5243	6

Based on the rank of the alternatives and considering that Al#2 is selected, the personnel will visit first the system *c*6 and then *c*5 the next day. The information about the time instants of the maintenance activities is presented in Table 21.

Table 21. Information about the time instants of maintenance activities at Test_case#1 Iteration#1.

Information	*c*5	*c*6
Current time	17:23	17:23

Detection time	17:23	17:23
Day of repairment	d2	d2
Date of repairment	16/05/2020	16/05/2020
Selected team	*p2*	*p2*
Start time of the trip	05:41	00:00
Traveling time (min)	0	41
Repairment time	8	5
End of repairment	13:41	05:41

4.1.2 Iteration#2

At 18:49, two new tickets open referring to systems *c*1 and *c*2. At Iteration#1 we selected Al#2, so the maintenance of previous tickets has not started yet. Consequently, at this iteration, for the alternatives' formulation, we take into account the systems *c*5 and *c*6 as well. Since we have 840 alternatives at Iteration#2, for sake of simplicity Table 22 illustrates only the ten best alternatives at a decent order, considering the rank number.

Table 22. Alternatives at Test_Case#1 Iteration#2.

Alternative No.	Team	Day	Route
Al#217	*p1*	*d2*	*c7->c5*
	p1	*d2*	*c5->c6*
	p2	*d2*	*c7->c1*
	p2	*d2*	*c1->c2*
Al#218	*p1*	*d2*	*c7->c5*
	p1	*d2*	*c5->c6*
	p2	*d2*	*c7->c2*
	p2	*d2*	*c2->c1*
Al#247	*p1*	*d2*	*c7->c1*
	p1	*d2*	*c1->c2*
	p2	*d2*	*c7->c5*
	p2	*d2*	*c5->c6*
Al#248	*p1*	*d2*	*c7->c1*
	p1	*d2*	*c1->c2*
	p2	*d2*	*c7->c6*
	p2	*d2*	*c6->c5*
Al#262	*p1*	*d2*	*c7->c6*
	p1	*d2*	*c6->c5*
	p2	*d2*	*c7->c1*

	p2	*d2*	*c1->c2*
AI#263	*p1*	*d2*	*c7->c6*
	p1	*d2*	*c6->c5*
	p2	*d2*	*c7->c2*
	p2	*d2*	*c2->c1*
AI#292	*p1*	*d2*	*c7->c2*
	p1	*d2*	*c2->c1*
	p2	*d2*	*c7->c5*
	p2	*d2*	*c5->c6*
AI#293	*p1*	*d2*	*c7->c2*
	p1	*d2*	*c2->c1*
	p2	*d2*	*c7->c6*
	p2	*d2*	*c6->c5*
AI#173	*p1*	*d2*	*c7->c1*
	p2	*d2*	*c7->c2*
	p2	*d2*	*c2->c5*
	p2	*d2*	*c5->c6*
AI#174	*p1*	*d2*	*c7->c1*
	p2	*d2*	*c7->c2*
	p2	*d2*	*c2->c6*
	p2	*d2*	*c6->c5*

Table 23. Criteria and alternatives at Test_case#1 Iteration#2.

	Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#217	*p1*	*d2*	*c7->c5*	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p1	*d2*	*c5->c6*	0	0	Asphalt	Medium	Medium	Competent	Medium	8,683	13,683	13,683	0	High	Marginal	Cloudy
	p2	*d2*	*c7->c1*	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p2	*d2*	*c1->c2*	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,200	10,200	0	High	Marginal	Sunny
AI#218	*p1*	*d2*	*c7->c5*	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p1	*d2*	*c5->c6*	0	0	Asphalt	Medium	Medium	Competent	Medium	8,683	13,683	13,683	0	High	Marginal	Cloudy
	p2	*d2*	*c7->c2*	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p2	*d2*	*c2->c1*	0	0	Asphalt	Medium	High	Expert	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
AI#247	*p1*	*d2*	*c7->c1*	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p1	*d2*	*c1->c2*	0	0	Asphalt	Low	Medium	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
	p2	*d2*	*c7->c5*	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	*d2*	*c5->c6*	0	0	Asphalt	Medium	Medium	Expert	Medium	8,683	13,683	13,683	0	High	Marginal	Cloudy

AI#248	p1	d2	c7->c1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p1	d2	c1->c2	0	0	Asphalt	Low	Medium	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
	p2	d2	c7->c6	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p2	d2	c6->c5	0	0	Asphalt	High	High	Expert	Medium	5,683	13,683	13,683	0	High	Catastrophic	Cloudy
AI#262	p1	d2	c7->c6	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p1	d2	c6->c5	0	0	Asphalt	High	High	Competent	Medium	5,683	13,683	13,683	0	High	Catastrophic	Cloudy
	p2	d2	c7->c1	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p2	d2	c1->c2	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,200	10,200	0	High	Marginal	Sunny
AI#263	p1	d2	c7->c6	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p1	d2	c6->c5	0	0	Asphalt	High	High	Competent	Medium	5,683	13,683	13,683	0	High	Catastrophic	Cloudy
	p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p2	d2	c2->c1	0	0	Asphalt	Medium	High	Expert	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
AI#292	p1	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny

	p1	d2	c2->c1	0	0	Asphalt	Medium	High	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
	p2	d2	c7->c5	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	d2	c5->c6	0	0	Asphalt	Medium	Medium	Expert	Medium	8,683	13,683	13,683	0	High	Marginal	Cloudy
AI#293	p1	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p1	d2	c2->c1	0	0	Asphalt	Medium	High	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
	p2	d2	c7->c6	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	5,683	5,683	0	High	Marginal	Cloudy
	p2	d2	c6->c5	0	0	Asphalt	High	High	Expert	Medium	5,683	13,683	13,683	0	High	Catastrophic	Cloudy
AI#173	p1	d2	c7->c1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p2	d2	c2->c5	26,4	39	Asphalt	High	High	Expert	Medium	5,2	13,850	8,650	0	High	Catastrophic	Cloudy
	p2	d2	c5->c6	0	0	Asphalt	Medium	Medium	Expert	Medium	13,85	18,850	13,650	0	High	Marginal	Cloudy
AI#174	p1	d2	c7->c1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
	p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0,000	5,200	5,200	0	High	Marginal	Sunny

	p2	*d2*	*c2->c6*	26,4	39	Asphalt	Medium	Medium	Expert	Medium	5,200	10,850	5,650	0	High	Marginal	Cloudy
	p2	*d2*	*c6->c5*	0	0	Asphalt	High	High	Expert	Medium	10,850	18,850	13,650	0	High	Catastrophic	Cloudy

The values of the criteria for the individual routes of the alternatives are presented in Table 23. Additionally, in Table 24 we have converted the qualitative criteria with the ranged values and we provide the summary of the criteria for each alternative. The summary of the criteria has been explicitly described in section 4.1.1. Furthermore, the decision matrix, the normalized decision matrix, as well as the weighted normalized matrix are presented in Table 25, Table 26 and Table 27 respectively. Additionally, the ideal and the anti-ideal solutions are illustrated in Table 28.

Finally, the distances between each alternative with the ideal solution and the anti-deal solution, the relative closeness of each alterative to the ideal solution and the rank number of the alternatives are presented in Table 29. Based on the ranking number we can conclude that the best alternatives are those with the minimum travelling distance. This was occurred at the previous iteration as well.

Table 24. Criteria and alternatives with numerical values at Test_case#1 Iteration#2.

	Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
	p1	d2	c7->c5	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p1	d2	c5->c6	0	0	8	5	5	5	5	8,683	13,683	13,683	0	8	4	7
AI#217	p2	d2	c7->c1	6,3	12	8	5	8	8	5	0	5,200	5,200	0	8	4	9
	p2	d2	c1->c2	0	0	8	2	5	8	5	5,2	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	13,883	13,683	0	0	8	5	8
	p1	d2	c7->c5	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p1	d2	c5->c6	0	0	8	5	5	5	5	8,683	13,683	13,683	0	8	4	7
AI#218	p2	d2	c7->c2	6,3	12	8	2	5	8	5	0	5,200	5,200	0	8	4	9
	p2	d2	c2->c1	0	0	8	5	8	8	5	5,200	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	13,883	13,683	0	0	8	5	8
	p1	d2	c7->c1	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p1	d2	c1->c2	0	0	8	2	5	5	5	5,200	10,200	10,200	0	8	4	9
AI#247	p2	d2	c7->c5	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
	p2	d2	c5->c6	0	0	8	5	5	8	5	8,683	13,683	13,683	0	8	4	7
				33,6	53	8	5	6	6	5	13,883	13,683	0	0	8	5	8
	p1	d2	c7->c1	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p1	d2	c1->c2	0	0	8	2	5	5	5	5,200	10,200	10,200	0	8	4	9
AI#248	p2	d2	c7->c6	27,3	41	8	5	5	8	5	0	5,683	5,683	0	8	4	7
	p2	d2	c6->c5	0	0	8	8	8	8	5	5,683	13,683	13,683	0	8	8	7
				33,6	53	8	5	6	6	5	10,883	13,683	0	0	8	5	8
	p1	d2	c7->c6	27,3	41	8	5	5	5	5	0	5,683	5,683	0	8	4	7
	p1	d2	c6->c5	0	0	8	8	8	5	5	5,683	13,683	13,683	0	8	8	7
AI#262	p2	d2	c7->c1	6,3	12	8	5	8	8	5	0	5,200	5,200	0	8	4	9
	p2	d2	c1->c2	0	0	8	2	5	8	5	5,2	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	10,883	13,683	0	0	8	5	8
	p1	d2	c7->c6	27,3	41	8	5	5	5	5	0	5,683	5,683	0	8	4	7
AI#263	p1	d2	c6->c5	0	0	8	8	8	5	5	5,683	13,683	13,683	0	8	8	7
	p2	d2	c7->c2	6,3	12	8	2	5	8	5	0	5,200	5,200	0	8	4	9

	p2	*d2*	*c2->c1*	0	0	8	5	8	8	5	5,200	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	10,883	13,683	0	0	8	5	8
	p1	*d2*	*c7->c2*	6,3	12	8	2	5	5	5	0	5,200	5,200	0	8	4	9
	p1	*d2*	*c2->c1*	0	0	8	5	8	5	5	5,200	10,200	10,200	0	8	4	9
AI#292	*p2*	*d2*	*c7->c5*	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
	p2	*d2*	*c5->c6*	0	0	8	5	5	8	5	8,683	13,683	13,683	0	8	4	7
				33,6	53	8	5	6	6	5	13,883	13,683	0	0	8	5	8
	p1	*d2*	*c7->c2*	6,3	12	8	2	5	5	5	0	5,200	5,200	0	8	4	9
	p1	*d2*	*c2->c1*	0	0	8	5	8	5	5	5,200	10,200	10,200	0	8	4	9
AI#293	*p2*	*d2*	*c7->c6*	27,3	41	8	5	5	8	5	0	5,683	5,683	0	8	4	7
	p2	*d2*	*c6->c5*	0	0	8	8	8	8	5	5,683	13,683	13,683	0	8	8	7
				33,6	53	8	5	6	6	5	10,883	13,683	0	0	8	5	8
	p1	*d2*	*c7->c1*	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c7->c2*	6,3	12	8	2	5	8	5	0	5,200	5,200	0	8	4	9
AI#173	*p2*	*d2*	*c2->c5*	26,4	39	8	8	8	8	5	5,2	13,850	8,650	0	8	8	7
	p2	*d2*	*c5->c6*	0	0	8	5	5	8	5	13,85	18,850	13,650	0	8	4	7
				39	63	8	5	6	7	5	19,050	18,850	0	0	8	5	8
	p1	*d2*	*c7->c1*	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c7->c2*	6,3	12	8	2	5	8	5	0,000	5,200	5,200	0	8	4	9
AI#174	*p2*	*d2*	*c2->c6*	26,4	39	8	5	5	8	5	5,200	10,850	5,650	0	8	4	7
	p2	*d2*	*c6->c5*	0	0	8	8	8	8	5	10,850	18,850	13,650	0	8	8	7
				39	63	8	5	6	7	5	16,050	18,850	0	0	8	5	8

Table 25. Decision matrix (X) at Test_case#1 Iteration#2.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#217	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#218	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#247	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#248	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#262	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#263	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#292	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#293	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#173	9	9	8	5	6	7	5	6	1	9	9	8	5	8
AI#174	9	9	8	5	6	7	5	6	1	9	9	8	5	8

Table 26. Normalized decision matrix (R) at Test_case#1 Iteration#2.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#217	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034
AI#218	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034

AI#247	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034
AI#248	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034
AI#262	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034
AI#263	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034
AI#292	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034
AI#293	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,036	0,009	0,106	0,035	0,035	0,035	0,034
AI#173	0,055	0,056	0,035	0,035	0,035	0,038	0,027	0,031	0,009	0,106	0,035	0,035	0,035	0,034
AI#174	0,055	0,056	0,035	0,035	0,035	0,038	0,027	0,031	0,009	0,106	0,035	0,035	0,035	0,034

Table 27. Weighted matrix (V) at Test_case#1 Iteration#2.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#217	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#218	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#247	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#248	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#262	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#263	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#292	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#293	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
AI#173	0,004	0,004	0,002	0,002	0,002	0,003	0,002	0,002	0,001	0,008	0,002	0,002	0,002	0,002
AI#174	0,004	0,004	0,002	0,002	0,002	0,003	0,002	0,002	0,001	0,008	0,002	0,002	0,002	0,002

Table 28. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#1 Iteration#2.

Criterion code	A^+	A^-
z1	0,0039	0,0004
z2	0,0040	0,0004
z3	0,0025	0,0025
z4	0,0025	0,0025
z5	0,0025	0,0025
z6	0,0031	0,0019
z7	0,0031	0,0019
z8	0,0034	0,0004
z8	0,0057	0,0006
z10	0,0076	0,0008
z11	0,0025	0,0025
z12	0,0025	0,0025
z13	0,0025	0,0025
z14	0,0028	0,0022

Table 29. Ranking of maintenance plans at Test_case#1 Iteration#2.

Alternatives Code	d^+	d^-	RC	Rank
Al#217	0,0053	0,0087	0,6196	1
Al#218	0,0053	0,0087	0,6196	1
Al#247	0,0053	0,0087	0,6196	1
Al#248	0,0053	0,0087	0,6196	1
Al#262	0,0053	0,0087	0,6196	1
Al#263	0,0053	0,0087	0,6196	1
Al#292	0,0053	0,0087	0,6196	1
Al#293	0,0053	0,0087	0,6196	1
Al#173	0,0054	0,0086	0,6168	9
Al#174	0,0054	0,0086	0,6168	9

Based on the ranking numbers of Table 29 it is clear that eight out of ten best alternatives have rank number 1. Considering the detailed illustration of the alternatives at Table 24, the only difference between these alternatives is observed at the unavailability time of the personnel. However, based on the normalized decision matrix (Table 25), there are no differences between the ranged values of the personnel unavailability, even if at alternatives Al#248, Al#262, Al#263 and Al#293 the time of personnel unavailability is lower (Table 24). This is one of the main disadvantages of the method, since the user will not be able to see the detailed information of the alternatives and will have to select the optimal alternative based only on the rank number.

At this iteration we select Al#248. The detailed information about the maintenance activities is presented in Table 30.

Table 30. Information about the time of maintenance activities at Test_case#1 Iteration#2.

Information	*c*1	*c*2	*c*5	*c*6
Current time	18:49	18:49	17:23	17:23
Detection time	18:49	18:49	17:23	17:23
Day of repairment	*d*2	*d*2	*d*2	*d*2
Date of repairment	16/05/2020	16/05/2020	16/05/2020	16/05/2020
Selected team	*p*1	*p*1	*p*2	*p*2
Start time of the trip	00:00	5:12	07:41	00:00
Traveling time (min)	12	0	0	41
Repairment time	5	5	8	5
End of repairment	5:12	10:12	15:41	05:41

4.1.3 Iteration#3

The model is executed again at 19:18, since a new ticket opens, referring again at system *c*6. As Iteration#2, at Iteration#3 we have to deal with all previous tickets since none of the maintenance activities have started yet. Additionally, since the first fault of the system *c*6 has not been repaired, the information of the two faults provided to the algorithm are merged. Specifically, as presented in Table 31, at the 'Total information' the values of the repairment time and the unavailability of spare parts are the total time required for the repairment of the individual faults and the total time required for the transportation of the missing spare parts, respectively. The value of the forecasted PV power does not differ between the two faults, since they refer to the same system. Finally, the fault severity is set equal to the maximum value of the two faults.

Table 31. Tickets and merged information for system *c*6.

Faulty system	System-Location code	Value of fault severity	Value of average forecasted power	Transportation time of spare parts	Time to repair (h)
Eragro_6	*c*6	4	8	0	5
Eragro_6	*c*6	2	8	0	2
Total information		4	8	0	7

Since the faulty systems are the same as Iteration#2, the alternatives and the number of alternatives remain the same. For shake of simplicity, we present again the ten best alternatives (Table 32), in terms of the rank number with a decent order.

Table 32. Alternatives at Test_Case#1 Iteration#3.

Alternative No.	Team	Day	Route
Al#217	*p*1	*d*2	*c*7->*c*5
	*p*1	*d*2	*c*5->*c*6
	*p*2	*d*2	*c*7->*c*1
	*p*2	*d*2	*c*1->*c*2
Al#218	*p*1	*d*2	*c*7->*c*5
	*p*1	*d*2	*c*5->*c*6
	*p*2	*d*2	*c*7->*c*2
	*p*2	*d*2	*c*2->*c*1
Al#247	*p*1	*d*2	*c*7->*c*1
	*p*1	*d*2	*c*1->*c*2
	*p*2	*d*2	*c*7->*c*5
	*p*2	*d*2	*c*5->*c*6
Al#248	*p*1	*d*2	*c*7->*c*1
	*p*1	*d*2	*c*1->*c*2
	*p*2	*d*2	*c*7->*c*6

	p2	d2	c6->c5
AI#262	p1	d2	c7->c6
	p1	d2	c6->c5
	p2	d2	c7->c1
	p2	d2	c1->c2
AI#263	p1	d2	c7->c6
	p1	d2	c6->c5
	p2	d2	c7->c2
	p2	d2	c2->c1
AI#292	p1	d2	c7->c2
	p1	d2	c2->c1
	p2	d2	c7->c5
	p2	d2	c5->c6
AI#293	p1	d2	c7->c2
	p1	d2	c2->c1
	p2	d2	c7->c6
	p2	d2	c6->c5
AI#173	p1	d2	c7->c1
	p2	d2	c7->c2
	p2	d2	c2->c5
	p2	d2	c5->c6
AI#174	p1	d2	c7->c1
	p2	d2	c7->c2
	p2	d2	c2->c6
	p2	d2	c6->c5

The values of the criteria for each individual route of the alternatives are presented in Table 33. Moreover, Table 34 includes the ranged values of the criteria and provides the summary for each alternative. The decision matrix, the normalized decision matrix and the weighted normalized matrix are presented in Table 35, Table 36 and Table 37, respectively. Additionally, the ideal and the anti-ideal solutions are illustrated in Table 38.

Finally, the distances between each alternative with the ideal-solution and the anti-deal solution, the relative closeness of each alterative to the ideal solution and the rank number of the alternatives are presented in Table 39. Considering the rank number, we can conclude that the best alternatives are those with the minimum travelling distance. This was occurred at the previous iteration as well. Furthermore, the same issue with multiple alternatives sharing the same rank number is also observed at the present iteration. Additionally, even if the ticket of *c*6 has changed in order to include the information of two faults, the rank number of the best alternatives have not changed compared to Iteration#2.

At this iteration it is assumed that Al#248 is selected. The detailed information about the maintenance activities is presented in Table 40.

Table 33. Criteria and alternatives at Test_case#1 Iteration#3.

Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
*p*1	*d*2	*c*7->*c*5	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
*p*1	*d*2	*c*5->*c*6	0	0	Asphalt	Medium	Medium	Competent	Medium	8,683	15,683	15,683	0	High	Marginal	Cloudy
*p*2	*d*2	*c*7->*c*1	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
*p*2	*d*2	*c*1->*c*2	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,200	10,200	0	High	Marginal	Sunny
*p*1	*d*2	*c*7->*c*5	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
*p*1	*d*2	*c*5->*c*6	0	0	Asphalt	Medium	Medium	Competent	Medium	8,683	15,683	15,683	0	High	Marginal	Cloudy
*p*2	*d*2	*c*7->*c*2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
*p*2	*d*2	*c*2->*c*1	0	0	Asphalt	Medium	High	Expert	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
*p*1	*d*2	*c*7->*c*1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
*p*1	*d*2	*c*1->*c*2	0	0	Asphalt	Low	Medium	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
*p*2	*d*2	*c*7->*c*5	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
*p*2	*d*2	*c*5->*c*6	0	0	Asphalt	Medium	Medium	Expert	Medium	8,683	15,683	15,683	0	High	Marginal	Cloudy
*p*1	*d*2	*c*7->*c*1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
*p*1	*d*2	*c*1->*c*2	0	0	Asphalt	Low	Medium	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
*p*2	*d*2	*c*7->*c*6	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	7,683	7,683	0	High	Marginal	Cloudy
*p*2	*d*2	*c*6->*c*5	0	0	Asphalt	High	High	Expert	Medium	7,683	15,683	15,683	0	High	Catastrophic	Cloudy
*p*1	*d*2	*c*7->*c*6	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	7,683	7,683	0	High	Marginal	Cloudy
*p*1	*d*2	*c*6->*c*5	0	0	Asphalt	High	High	Competent	Medium	7,683	15,683	15,683	0	High	Catastrophic	Cloudy
*p*2	*d*2	*c*7->*c*1	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
*p*2	*d*2	*c*1->*c*2	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,200	10,200	0	High	Marginal	Sunny

p1	d2	c7->c6	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	7,683	7,683	0	High	Marginal	Cloudy
p1	d2	c6->c5	0	0	Asphalt	High	High	Competent	Medium	7,683	15,683	15,683	0	High	Catastrophic	Cloudy
p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
p2	d2	c2->c1	0	0	Asphalt	Medium	High	Expert	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
p1	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
p1	d2	c2->c1	0	0	Asphalt	Medium	High	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
p2	d2	c7->c5	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
p2	d2	c5->c6	0	0	Asphalt	Medium	Medium	Expert	Medium	8,683	15,683	15,683	0	High	Marginal	Cloudy
p1	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
p1	d2	c2->c1	0	0	Asphalt	Medium	High	Competent	Medium	5,200	10,200	10,200	0	High	Marginal	Sunny
p2	d2	c7->c6	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	7,683	7,683	0	High	Marginal	Cloudy
p2	d2	c6->c5	0	0	Asphalt	High	High	Expert	Medium	7,683	15,683	15,683	0	High	Catastrophic	Cloudy
p1	d2	c7->c1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,200	5,200	0	High	Marginal	Sunny
p2	d2	c2->c5	26,4	39	Asphalt	High	High	Expert	Medium	5,2	13,850	13,850	0	High	Catastrophic	Cloudy
p2	d2	c5->c6	0	0	Asphalt	Medium	Medium	Expert	Medium	13,85	20,850	20,850	0	High	Marginal	Cloudy
p1	d2	c7->c1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,200	5,200	0	High	Marginal	Sunny
p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0,000	5,200	5,200	0	High	Marginal	Sunny
p2	d2	c2->c6	26,4	39	Asphalt	Medium	Medium	Expert	Medium	5,200	12,850	12,850	0	High	Marginal	Cloudy
p2	d2	c6->c5	0	0	Asphalt	High	High	Expert	Medium	12,850	20,850	20,850	0	High	Catastrophic	Cloudy

Table 34. Criteria and alternatives with numerical values at Test_case#1 Iteration#3.

	Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
	p1	*d2*	*c7->c5*	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p1	*d2*	*c5->c6*	0	0	8	5	5	5	5	8,683	15,683	15,683	0	8	4	7
AI#217	*p2*	*d2*	*c7->c1*	6,3	12	8	5	8	8	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c1->c2*	0	0	8	2	5	8	5	5,2	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	13,883	15,683	0	0	8	5	8
	p1	*d2*	*c7->c5*	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p1	*d2*	*c5->c6*	0	0	8	5	5	5	5	8,683	15,683	15,683	0	8	4	7
AI#218	*p2*	*d2*	*c7->c2*	6,3	12	8	2	5	8	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c2->c1*	0	0	8	5	8	8	5	5,200	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	13,883	15,683	0	0	8	5	8
	p1	*d2*	*c7->c1*	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p1	*d2*	*c1->c2*	0	0	8	2	5	5	5	5,200	10,200	10,200	0	8	4	9
AI#247	*p2*	*d2*	*c7->c5*	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
	p2	*d2*	*c5->c6*	0	0	8	5	5	8	5	8,683	15,683	15,683	0	8	4	7
				33,6	53	8	5	6	6	5	13,883	15,683	0	0	8	5	8
	p1	*d2*	*c7->c1*	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p1	*d2*	*c1->c2*	0	0	8	2	5	5	5	5,200	10,200	10,200	0	8	4	9
AI#248	*p2*	*d2*	*c7->c6*	27,3	41	8	5	5	8	5	0	7,683	7,683	0	8	4	7
	p2	*d2*	*c6->c5*	0	0	8	8	8	8	5	7,683	15,683	15,683	0	8	8	7
				33,6	53	8	5	6	6	5	12,883	15,683	0	0	8	5	8
	p1	*d2*	*c7->c6*	27,3	41	8	5	5	5	5	0	7,683	7,683	0	8	4	7
	p1	*d2*	*c6->c5*	0	0	8	8	8	5	5	7,683	15,683	15,683	0	8	8	7
AI#262	*p2*	*d2*	*c7->c1*	6,3	12	8	5	8	8	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c1->c2*	0	0	8	2	5	8	5	5,2	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	12,883	15,683	0	0	8	5	8
	p1	*d2*	*c7->c6*	27,3	41	8	5	5	5	5	0	7,683	7,683	0	8	4	7
	p1	*d2*	*c6->c5*	0	0	8	8	8	5	5	7,683	15,683	15,683	0	8	8	7
AI#263	*p2*	*d2*	*c7->c2*	6,3	12	8	2	5	8	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c2->c1*	0	0	8	5	8	8	5	5,200	10,200	10,200	0	8	4	9
				33,6	53	8	5	6	6	5	12,883	15,683	0	0	8	5	8
	p1	*d2*	*c7->c2*	6,3	12	8	2	5	5	5	0	5,200	5,200	0	8	4	9
	p1	*d2*	*c2->c1*	0	0	8	5	8	5	5	5,200	10,200	10,200	0	8	4	9
AI#292	*p2*	*d2*	*c7->c5*	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
	p2	*d2*	*c5->c6*	0	0	8	5	5	8	5	8,683	15,683	15,683	0	8	4	7
				33,6	53	8	5	6	6	5	13,883	15,683	0	0	8	5	8
	p1	*d2*	*c7->c2*	6,3	12	8	2	5	5	5	0	5,200	5,200	0	8	4	9
	p1	*d2*	*c2->c1*	0	0	8	5	8	5	5	5,200	10,200	10,200	0	8	4	9
AI#293	*p2*	*d2*	*c7->c6*	27,3	41	8	5	5	8	5	0	7,683	7,683	0	8	4	7
	p2	*d2*	*c6->c5*	0	0	8	8	8	8	5	7,683	15,683	15,683	0	8	8	7
				33,6	53	8	5	6	6	5	12,883	15,683	0	0	8	5	8

AI#173	*p1*	*d2*	*c7->c1*	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c7->c2*	6,3	12	8	2	5	8	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c2->c5*	26,4	39	8	8	8	8	5	5,2	13,850	13,850	0	8	8	7
	p2	*d2*	*c5->c6*	0	0	8	5	5	8	5	13,85	20,850	20,850	0	8	4	7
				39	63	8	5	6	7	5	19,050	20,850	0	0	8	5	8
AI#174	*p1*	*d2*	*c7->c1*	6,3	12	8	5	8	5	5	0	5,200	5,200	0	8	4	9
	p2	*d2*	*c7->c2*	6,3	12	8	2	5	8	5	0,000	5,200	5,200	0	8	4	9
	p2	*d2*	*c2->c6*	26,4	39	8	5	5	8	5	5,200	12,850	12,850	0	8	4	7
	p2	*d2*	*c6->c5*	0	0	8	8	8	8	5	12,850	20,850	20,850	0	8	8	7
				39	63	8	5	6	7	5	18,050	20,850	0	0	8	5	8

Table 35. Decision matrix (X) at Test_case#1 Iteration#3.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#217	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#218	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#247	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#248	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#262	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#263	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#292	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#293	9	9	8	5	6	6	5	7	1	9	9	8	5	8
AI#173	9	9	8	5	6	7	5	6	1	9	9	8	5	8
AI#174	9	9	8	5	6	7	5	6	1	9	9	8	5	8

Table 36. Normalized decision matrix (R) at Test_case#1 Iteration#3.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#217	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#218	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#247	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#248	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#262	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#263	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#292	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#293	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,037	0,012	0,111	0,035	0,035	0,035	0,034
AI#173	0,055	0,056	0,035	0,035	0,035	0,038	0,027	0,032	0,012	0,111	0,035	0,035	0,035	0,034
AI#174	0,055	0,056	0,035	0,035	0,035	0,038	0,027	0,032	0,012	0,111	0,035	0,035	0,035	0,034

Table 37. Weighted matrix (V) at Test_case#1 Iteration#3.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#217	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002

Al#218	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
Al#247	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
Al#248	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
Al#262	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
Al#263	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
Al#292	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
Al#293	0,004	0,004	0,002	0,002	0,002	0,002	0,002	0,003	0,001	0,008	0,002	0,002	0,002	0,002
Al#173	0,004	0,004	0,002	0,002	0,002	0,003	0,002	0,002	0,001	0,008	0,002	0,002	0,002	0,002
Al#174	0,004	0,004	0,002	0,002	0,002	0,003	0,002	0,002	0,001	0,008	0,002	0,002	0,002	0,002

Table 38. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#1 Iteration#3.

Criterion code	A^+	A^-
z1	0,0039	0,0004
z2	0,0040	0,0004
z3	0,0025	0,0025
z4	0,0025	0,0025
z5	0,0025	0,0025
z6	0,0031	0,0019
z7	0,0031	0,0019
z8	0,0034	0,0004
z8	0,0079	0,0009
z10	0,0079	0,0009
z11	0,0025	0,0025
z12	0,0025	0,0025
z13	0,0025	0,0025
z14	0,0028	0,0022

Table 39. Ranking of maintenance plans at Test_case#1 Iteration#3.

Alternatives Code	d^+	d^-	RC	Rank
Al#217	0,0072	0,0089	0,5531	1
Al#218	0,0072	0,0089	0,5531	1
Al#247	0,0072	0,0089	0,5531	1
Al#248	0,0072	0,0089	0,5531	1
Al#262	0,0072	0,0089	0,5531	1
Al#263	0,0072	0,0089	0,5531	1
Al#292	0,0072	0,0089	0,5531	1

AI#293	0,0072	0,0089	0,5531	1
AI#173	0,0072	0,0089	0,5508	9
AI#174	0,0072	0,0089	0,5508	9

Table 40. Information about the time of maintenance activities at Test_case#1 Iteration#3.

Information	***c*1**	***c*2**	***c*5**	***c*6**
Current time	19:18	19:18	19:18	19:18
Detection time	18:49	18:49	17:23	19:18
Day of repairment	*d*2	*d*2	*d*2	*d*2
Date of repairment	16/05/2020	16/05/2020	16/05/2020	16/05/2020
Selected team	*p*1	*p*1	*p*2	*p*2
Start time of the trip	00:00	5:12	05:41	00:00
Traveling time (min)	12	0	0	41
Repairment time	5	5	8	5
End of repairment	5:12	10:12	13:41	05:41

4.1.4 Iteration#4

At 16/05/2020 13:41, i.e., the time when the first sub-maintenance activity is completed, the MCDA tool is executed again in order to schedule the second sub-maintenance activity. Based on the alternative selected at Iteration#3, the functionality of systems *c*1, *c*2 and *c*6 have been restored and the tickets have closed. However, the ticket for *c*5 will not close since we have separated the maintenance into 6 sub-maintenance activities.

The location of team *p*2 is at *c*5 since the team finish the first maintenance part at 13:41. The alternatives are presented in Table 41. To this point it should be clarified that even if the indexes of the days remain the same, i.e., *d*1 and *d*2, they refer to different dates, i.e., 16/05/2020 and 17/05/2020 respectively, while the ticket opens at 15/05/2020. Based on this the 'Urgency' of the maintenance are updated to 'Medium' and 'High' for *d*1 and *d*2, respectively. Additionally, the information about the weather conditions and the forecasted PV power is updated, as presented in Table 42. The forecasting process is illustrated in Figure 2 and Figure 3. Specifically, in case we attempt to predict the PV power at a timestep when we do not have the required historical values, we use the forecasted values of PV power, solar irradiation and ambient temperature as inputs, as presented in Figure 3a. Moreover, for the forecasted meteorological conditions we use the actual values, assuming they are predictions.

Table 41. Alternatives at Test_Case#1 Iteration#4.

	Team	**Day**	**Route**
AI#1	*p*2	*d*2	*c*7->*c*5
AI#2	*p*2	*d*1	*c*5->*c*5
AI#3	*p*1	*d*2	*c*7->*c*5

AI#4	*p*1	*d*1	*c*7->*c*5

Table 42. Criteria in terms of repairment day for Test_case#1 at Iteration#4.

Repairment day	Repairment day	System-Location code	Urgency	Weather severity	Forecasted PV power
16/05/2020	*d*1	*c*5	Medium	Cloudy	High
17/05/2020	*d*2	*c*5	High	Sunny	High

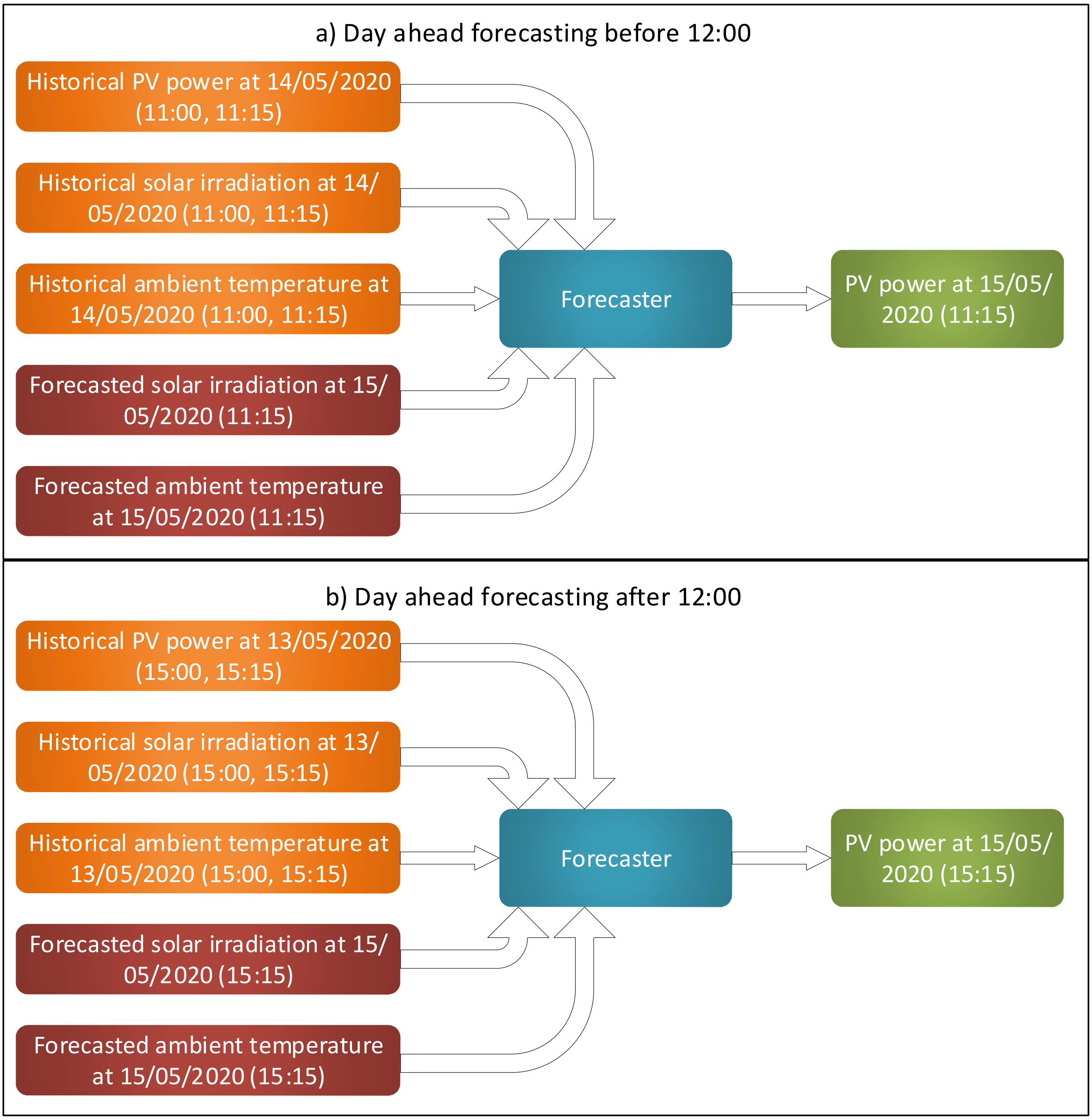

Figure 2. Day ahead PV power forecasting

Table 43 and Table 44 present the criteria and the alternatives before and after the conversion of the qualitative criteria into ranged values. The decision matrix, the normalized decision matrix and the weighted normalized decision matrix are illustrated in Table 45, Table 46 and Table 47, respectively. Moreover, the ideal and anti-ideal solution of the alternatives are included in Table 48. Finally, Table 49 demonstrates the distances between each alternative with the ideal-solution and the anti-deal solution, the relative closeness of each alterative to the ideal solution and the rank number of the alternatives.

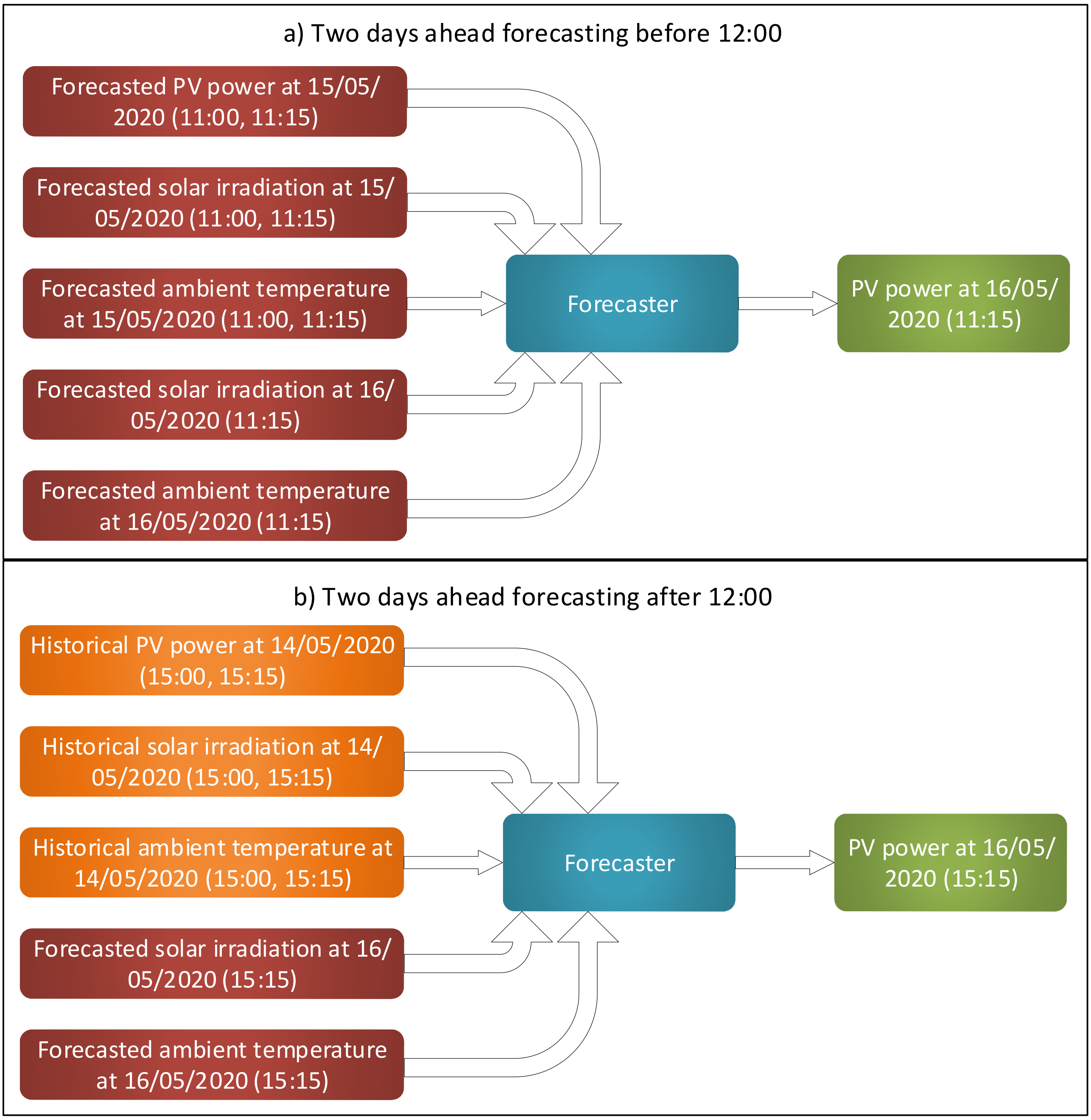

Figure 3. Two days ahead PV power forecasting: a) before 12:00, b) after 12:00.

Table 43. Criteria and alternatives at Test_case#1 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	22,367	0	High	Catastrophic	Sunny
AI#2	0	0	Asphalt	High	High	Competent	High	0	18,200	8,000	0	High	Catastrophic	Cloudy
AI#3	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	22,367	0	High	Catastrophic	Sunny
AI#4	27,3	41	Asphalt	High	High	Expert	High	0	24,366	8,683	0	High	Catastrophic	Cloudy

Table 44. Criteria and alternatives with numerical values at Test_case#1 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	8	8	8	8	3	0	8,683	0	0	8	8	9
AI#2	0	0	8	8	8	8	5	0	18,2	0	0	8	8	7
AI#3	27,3	41	8	8	8	5	3	0	8,683	0	0	8	8	9
AI#4	27,3	41	8	8	8	5	5	0	24,36	0	0	8	8	7

Table 45. Decision matrix (X) at Test_case#1 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	1	1	8	8	8	8	3	9	9	9	9	8	8	9
AI#2	9	9	8	8	8	8	5	9	1	9	9	8	8	7
AI#3	1	1	8	8	8	5	3	9	9	9	9	8	8	9
AI#4	1	1	8	8	8	5	5	9	1	9	9	8	8	7

Table 46. Normalized decision matrix (R) at Test_case#1 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,109	0,109	0,500	0,500	0,500	0,600	0,364	0,500	0,703	0,500	0,500	0,500	0,500	0,558
AI#2	0,982	0,982	0,500	0,500	0,500	0,600	0,606	0,500	0,078	0,500	0,500	0,500	0,500	0,434
AI#3	0,109	0,109	0,500	0,500	0,500	0,375	0,364	0,500	0,703	0,500	0,500	0,500	0,500	0,558
AI#4	0,109	0,109	0,500	0,500	0,500	0,375	0,606	0,500	0,078	0,500	0,500	0,500	0,500	0,434

Table 47. Weighted matrix (V) at Test_case#1 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,008	0,008	0,036	0,036	0,036	0,043	0,026	0,036	0,050	0,036	0,036	0,036	0,036	0,040
AI#2	0,070	0,070	0,036	0,036	0,036	0,043	0,043	0,036	0,006	0,036	0,036	0,036	0,036	0,031
AI#3	0,008	0,008	0,036	0,036	0,036	0,027	0,026	0,036	0,050	0,036	0,036	0,036	0,036	0,040
AI#4	0,008	0,008	0,036	0,036	0,036	0,027	0,043	0,036	0,006	0,036	0,036	0,036	0,036	0,031

Table 48. Ideal (A^{+}) and the anti-ideal (A^{-}) solutions at Test_case#1 Iteration#4.

Criterion code	A^{+}	A^{-}
z1	0,0701	0,0078
z2	0,0701	0,0078
z3	0,0357	0,0357
z4	0,0357	0,0357
z5	0,0357	0,0357
z6	0,0428	0,0268
z7	0,0433	0,0260
z8	0,0357	0,0357
z8	0,0502	0,0056
z10	0,0357	0,0357
z11	0,0357	0,0357
z12	0,0357	0,0357
z13	0,0357	0,0357
z14	0,0399	0,0310

Table 49. Ranking of maintenance plans at Test_case#1 Iteration#4.

Alternatives Code	d^{+}	d^{-}	RC	Rank
Al#1	0,0899	0,0482	0,3493	2
Al#2	0,0455	0,0913	0,6674	1
Al#3	0,0913	0,0455	0,3326	3
Al#4	0,1005	0,0173	0,1470	4

Based on the ranking number the best alternative is Al#2. However, considering the daily working hours of the personnel, i.e., Table 44 criterion z9, if we select Al#2 the total working hours of team *p*2 will be 18,2, which is extremely high. It is obvious that the rank number is mainly affected of the travelling distance and the travelling time, meaning that the optimal alternatives are those with the minimum distance and the minimum travelling time between the locations. This was noticeable at the previous iterations as well.

Except for the rank number we take into consideration the daily working hours and we select Al#1, which is the second best alternative. Even if the maintenance of the system is postponed for the next day (17/05/2020), the rank number derives based on the high complexity of the system (High) and the expertise of the personnel, i.e., the expertise of *p*2 is set to 'Expert'. The information of the maintenance activities is presented in Table 50.

Table 50. Information about the time of maintenance activities at Test_case#1 Iteration#4.

Information	*c5*
Current time	13:41
Day of repairment	*d2*
Date of repairment	17/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.1.5 Iteration#5

When the second sub-maintenance activity of *c*6 is over the model is executed again at 16/05/2020 8:41 in order to schedule the third one. The 'Urgency' criterion as well as the weather severity change according to the dates the model refers to, as it is demonstrated in Table 51. The alternatives remain the same as presented in Table 41 since they refer to the same system. At Table 52 the values of the criteria for each alternative are illustrated. Compared to the values of Iteration#4 (Table 43) the only differences are observed at criteria z9, i.e., daily working hours of personnel, and z10, i.e., the end time of maintenance activities.

The arithmetical values of the criteria are demonstrated in Table 53. Additionally, at Table 54, Table 55 and Table 56, the decision matrix, the normalized decision matrix and the weighted normalized decision matrix are presented, respectively, while the ideal and the anti-ideal solutions of the criteria are included in Table 57. Finally, the distances between each alternative with the ideal-solution and the anti-deal solution, the relative closeness of each alterative to the ideal solution and the rank number of the alternatives are illustrated in Table 58.

Table 51. Criteria in terms of repairment day for Test_case#1 at Iteration#5.

Repairment day	Repairment day	System-Location code	Urgency	Weather severity	Forecasted PV power
17/05/2020	*d*1	*c*5	High	Sunny	High
18/05/2020	*d*2	*c*5	High	Sunny	High

Table 52. Criteria and alternatives at Test_case#1 Iteration#5.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
Al#1	27,3	41	Asphalt	High	High	Competent	High	0	8,683	8,683	0	High	Catastrophic	Sunny
Al#2	0	0	Asphalt	High	High	Competent	High	0	16,683	16,683	0	High	Catastrophic	Sunny
Al#3	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	High	Catastrophic	Sunny
Al#4	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	High	Catastrophic	Sunny

Table 53. Criteria and alternatives with numerical values at Test_case#1 Iteration#5.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	8	8	8	8	3	0	8,683	0	0	8	8	9
AI#2	0	0	8	8	8	8	3	0	16,683	0	0	8	8	9
AI#3	27,3	41	8	8	8	5	3	0	8,683	0	0	8	8	9
AI#4	27,3	41	8	8	8	5	3	0	8,683	0	0	8	8	9

Table 54. Decision matrix (X) at Test_case#1 Iteration#5.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	1	1	8	8	8	8	3	9	9	9	9	8	8	9
AI#2	9	9	8	8	8	8	3	9	1	9	9	8	8	9
AI#3	1	1	8	8	8	5	3	9	9	9	9	8	8	9
AI#4	1	1	8	8	8	5	3	9	9	9	9	8	8	9

Table 55. Normalized decision matrix (R) at Test_case#1 Iteration#5.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,109	0,109	0,500	0,500	0,500	0,600	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,500
AI#2	0,982	0,982	0,500	0,500	0,500	0,600	0,500	0,500	0,064	0,500	0,500	0,500	0,500	0,500
AI#3	0,109	0,109	0,500	0,500	0,500	0,375	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,500
AI#4	0,109	0,109	0,500	0,500	0,500	0,375	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,500

Table 56. Weighted matrix (V) at Test_case#1 Iteration#5.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,008	0,008	0,036	0,036	0,036	0,043	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,036
AI#2	0,070	0,070	0,036	0,036	0,036	0,043	0,036	0,036	0,005	0,036	0,036	0,036	0,036	0,036
AI#3	0,008	0,008	0,036	0,036	0,036	0,027	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,036
AI#4	0,008	0,008	0,036	0,036	0,036	0,027	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,036

Table 57. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#1 Iteration#5.

Criterion code	A^+	A^-
z1	0,0701	0,0078
z2	0,0701	0,0078
z3	0,0357	0,0357
z4	0,0357	0,0357
z5	0,0357	0,0357
z6	0,0428	0,0268
z7	0,0357	0,0357
z8	0,0357	0,0357

z8	0,0412	0,0046
z10	0,0357	0,0357
z11	0,0357	0,0357
z12	0,0357	0,0357
z13	0,0357	0,0357
z14	0,0357	0,0357

Table 58. Ranking of maintenance plans at Test_case#1 Iteration#5.

Alternatives Code	d^{+}	d^{-}	RC	**Rank**
Al#1	0,0882	0,0400	0,3118	2
Al#2	0,0366	0,0896	0,7101	1
Al#3	0,0896	0,0366	0,2899	3
Al#4	0,0896	0,0366	0,2899	3

The same issue about the optimal alternative and the total daily working hours is observed at the current iteration as well. The best alternative is the one with the minimum distance and travelling time, i.e., Al#2, although the number of working hours is extremely high. Another disadvantage of the model is observed at the rank numbers of Al#3 and Al#4. Although they maintenance activities refer to different days the alternatives have the same rank number, meaning that the model does not take into account the date of the repairment, when exceeds the three days from the fault detection, neither the energy losses due to faulty operation.

Apart from the rank number, considering the daily working hours we select Al#1. The information of the maintenance activities is presented in Table 59.

Table 59. Information about the time of maintenance activities at Test_case#1 Iteration#5.

Information	***c5***
Current time	08:41
Day of repairment	*d2*
Date of repayment	18/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.1.6 Iteration#6

At 18/06/2020 08:41 the model is executed again since the third sub-maintenance activity is completed and the fourth should be scheduled. More than two days have passed since the detection of the fault, so the 'Urgency' of both days, i.e., *d*1 and *d*2 is set equal to 'High' (Table 60). Additionally, the weather at 18/05 and 19/05 is sunny for both days. The alternatives of the current iteration are the same as the previous iterations (Table 41), i.e., Iteration#4 and Iteration#5. Additionally, although *d*1 and *d*2 refer to 18/05/2020 and 19/05/2020, respectively, the criteria and the alternatives of the current iteration (Table 61) are the same as Iteration#5 (Table 52). Consequently, the rest of the matrices, i.e., the decision matrix (Table 54), the normalized decision matrix (Table 55), the weighted decision matrix (Table 56), the ideal and inti-ideal solution of the alternatives (Table 57), as well as the rank number of the alternatives (Table 58) remain are the same as Iteration#5. As a matter of fact, at Table 62 the ranking number of the alternatives are presented.

Table 60. Criteria in terms of repairment day for Test_case#1 at Iteration#6.

Repairment day	Repairment day	System-Location code	Urgency	Weather severity	Forecasted PV power
18/05/2020	*d*1	*c*5	High	Sunny	High
19/05/2020	*d*2	*c*5	High	Sunny	High

Table 61. Criteria and alternatives at Test_case#1 Iteration#6.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	Asphalt	High	High	Competent	High	0	8,683	8,683	0	High	Catastrophic	Sunny
AI#2	0	0	Asphalt	High	High	Competent	High	0	16,683	16,683	0	High	Catastrophic	Sunny
AI#3	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	High	Catastrophic	Sunny
AI#4	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	High	Catastrophic	Sunny

Table 62. Ranking of maintenance plans at Test_case#1 Iteration#6.

Alternatives Code	d^{+}	d^{-}	RC	Rank
AI#1	0,0882	0,0400	0,3118	2
AI#2	0,0366	0,0896	0,7101	1
AI#3	0,0896	0,0366	0,2899	3
AI#4	0,0896	0,0366	0,2899	3

Once more, the first alternative is selected, considering the rank number and the daily working hours of the personnel. The details of the maintenance activities are presented in Table 63.

Table 63. Information about the time of maintenance activities at Test_case#1 Iteration#6.

Information	*c*5

Current time	08:41
Day of repairment	*d*2
Date of repayment	19/05/2020
Selected team	*p*2
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.1.7 Iteration#7

At Iteration#7, which is executed at 19/05/2020 08:41, we have to change the weather severity as well as the forecasted PV power at 20/05/2020. Specifically, at 20/05/2020, the weather severity is set to 'Cloudy' while the forecasted PV power is set to 'Low' since the mean value of the average forecasted PV power is lower than the average nominal capacity of the total systems. The changes of the criteria, in terms of repayment day, are presented in Table 64. The alternatives are still the same as the previous iterations (Table 41).

Since the values of two out of fourteen criteria have changed, the matrices of the method will change accordingly. The values of the criteria before and after the conversion of the qualitative criteria are presented in Table 65 and Table 66. Additionally, the decision matrix, the normalized decision matrix, the weighted normalized decision matrix and the ideal and the anti-ideal solutions of the criteria are presented in Table 67, Table 68, Table 69 and Table 70, respectively. Moreover, the distances between each alternative to the ideal and anti-ideal solution, the relative closeness and the rank number of the alternatives are presented in Table 71.

Table 64. Criteria in terms of repairment day for Test_case#1 at Iteration#7.

Repairment day	Repairment day	System-Location code	Urgency	Weather severity	Forecasted PV power
19/05/2020	*d*1	*c*5	High	Sunny	High
20/05/2020	*d*2	*c*5	High	Cloudy	Low

Table 65. Criteria and alternatives at Test_case#1 Iteration#7.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
Al#1	27,3	41	Asphalt	High	High	Competent	High	0	8,683	8,683	0	Low	Catastrophic	Cloudy
Al#2	0	0	Asphalt	High	High	Competent	High	0	16,683	16,683	0	Low	Catastrophic	Sunny
Al#3	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	Low	Catastrophic	Cloudy
Al#4	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	Low	Catastrophic	Sunny

Table 66. Criteria and alternatives with numerical values at Test_case#1 Iteration#7.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	8	8	8	8	3	0	8,683	0	0	3	8	7
AI#2	0	0	8	8	8	8	3	0	16,683	0	0	3	8	9
AI#3	27,3	41	8	8	8	5	3	0	8,683	0	0	3	8	7
AI#4	27,3	41	8	8	8	5	3	0	8,683	0	0	3	8	9

Table 67. Decision matrix (X) at Test_case#1 Iteration#7.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	1	1	8	8	8	8	3	9	9	9	9	3	8	7
AI#2	9	9	8	8	8	8	3	9	1	9	9	3	8	9
AI#3	1	1	8	8	8	5	3	9	9	9	9	3	8	7
AI#4	1	1	8	8	8	5	3	9	9	9	9	3	8	9

Table 68. Normalized decision matrix (R) at Test_case#1 Iteration#7.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,109	0,109	0,500	0,500	0,500	0,600	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,434
AI#2	0,982	0,982	0,500	0,500	0,500	0,600	0,500	0,500	0,064	0,500	0,500	0,500	0,500	0,558
AI#3	0,109	0,109	0,500	0,500	0,500	0,375	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,434
AI#4	0,109	0,109	0,500	0,500	0,500	0,375	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,558

Table 69. Weighted matrix (V) at Test_case#1 Iteration#7.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,008	0,008	0,036	0,036	0,036	0,043	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,031
AI#2	0,070	0,070	0,036	0,036	0,036	0,043	0,036	0,036	0,005	0,036	0,036	0,036	0,036	0,040
AI#3	0,008	0,008	0,036	0,036	0,036	0,027	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,031
AI#4	0,008	0,008	0,036	0,036	0,036	0,027	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,040

Table 70. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#1 Iteration#7.

Criterion code	A^+	A^-
z1	0,0701	0,0078
z2	0,0701	0,0078
z3	0,0357	0,0357
z4	0,0357	0,0357
z5	0,0357	0,0357
z6	0,0428	0,0268
z7	0,0357	0,0357
z8	0,0357	0,0357

z8	0,0412	0,0046
z10	0,0357	0,0357
z11	0,0357	0,0357
z12	0,0357	0,0357
z13	0,0357	0,0357
z14	0,0399	0,0310

Table 71. Ranking of maintenance plans at Test_case#1 Iteration#7.

Alternatives Code	d^+	d^-	RC	Rank
Al#1	0,0886	0,0400	0,3107	2
Al#2	0,0366	0,0901	0,7111	1
Al#3	0,0901	0,0366	0,2889	4
Al#4	0,0896	0,0376	0,2958	3

Based on the rank number and considering the total working hours of the personnel, we select Al#1. The details of the repairment activities are illustrated in Table 72.

Table 72. Information about the time of maintenance activities at Test_case#1 Iteration#7.

Information	*c5*
Current time	08:41
Day of repairment	*d2*
Date of repayment	20/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.1.8 Iteration#8

At the last iteration, the model is executed at 20/05/2020 08:41 and the last sub-maintenance activity should be scheduled. The criteria in terms of the repairment day are presented in Table 73. The alternatives remain the same as the previous iterations (Table 41). Additionally, the criteria and the alternatives are presented in Table 74, while Table 75 includes the criteria and the alternatives with the ranged values of the qualitative criteria. Table 76, Table 77 and Table 78 demonstrate the decision matrix, the normalized decision matrix and the weighted normalized matrix, respectively. Moreover, Table 79 illustrates the ideal and inti-ideal solutions of the criteria. Finally, in Table 80 the distances between each alternative with the ideal-solution and the anti-deal solution, the relative closeness of each alterative to the ideal solution and the rank number of the alternatives are presented.

Table 73. Criteria in terms of repairment day for Test_case#1 at Iteration#8.

Repairment day	Repairment day	System-Location code	Urgency	Weather severity	Forecasted PV power
20/05/2020	*d*1	*c*5	High	Cloudy	Low
21/05/2020	*d*2	*c*5	High	Sunny	High

Table 74. Criteria and alternatives at Test_case#1 Iteration#8.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	Asphalt	High	High	Competent	High	0	8,683	8,683	0	Low	Catastrophic	Sunny
AI#2	0	0	Asphalt	High	High	Competent	High	0	16,683	16,683	0	Low	Catastrophic	Cloudy
AI#3	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	Low	Catastrophic	Sunny
AI#4	27,3	41	Asphalt	High	High	Expert	High	0	8,683	8,683	0	Low	Catastrophic	Cloudy

Table 75. Criteria and alternatives with numerical values at Test_case#1 Iteration#8.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	8	8	8	8	3	0	8,683	0	0	3	8	9
AI#2	0	0	8	8	8	8	3	0	16,683	0	0	3	8	7
AI#3	27,3	41	8	8	8	5	3	0	8,683	0	0	3	8	9
AI#4	27,3	41	8	8	8	5	3	0	8,683	0	0	3	8	7

Table 76. Decision matrix (X) at Test_case#1 Iteration#8.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	1	1	8	8	8	8	3	9	9	9	9	3	8	9
AI#2	9	9	8	8	8	8	3	9	1	9	9	3	8	7
AI#3	1	1	8	8	8	5	3	9	9	9	9	3	8	9
AI#4	1	1	8	8	8	5	3	9	9	9	9	3	8	7

Table 77. Normalized decision matrix (R) at Test_case#1 Iteration#8.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,109	0,109	0,500	0,500	0,500	0,600	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,558
AI#2	0,982	0,982	0,500	0,500	0,500	0,600	0,500	0,500	0,064	0,500	0,500	0,500	0,500	0,434
AI#3	0,109	0,109	0,500	0,500	0,500	0,375	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,558
AI#4	0,109	0,109	0,500	0,500	0,500	0,375	0,500	0,500	0,576	0,500	0,500	0,500	0,500	0,434

Table 78. Weighted matrix (V) at Test_case#1 Iteration#8.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14

Al#1	0,008	0,008	0,036	0,036	0,036	0,043	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,040
Al#2	0,070	0,070	0,036	0,036	0,036	0,043	0,036	0,036	0,005	0,036	0,036	0,036	0,036	0,031
Al#3	0,008	0,008	0,036	0,036	0,036	0,027	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,040
Al#4	0,008	0,008	0,036	0,036	0,036	0,027	0,036	0,036	0,041	0,036	0,036	0,036	0,036	0,031

Table 79. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#1 Iteration#7.

Criterion code	A^+	A^-
z1	0,0701	0,0078
z2	0,0701	0,0078
z3	0,0357	0,0357
z4	0,0357	0,0357
z5	0,0357	0,0357
z6	0,0428	0,0268
z7	0,0357	0,0357
z8	0,0357	0,0357
z8	0,0412	0,0046
z10	0,0357	0,0357
z11	0,0357	0,0357
z12	0,0357	0,0357
z13	0,0357	0,0357
z14	0,0399	0,0310

Table 80. Ranking of maintenance plans at Test_case#1 Iteration#7.

Alternatives Code	d^+	d^-	RC	Rank
Al#1	0,0882	0,0409	0,3170	2
Al#2	0,0376	0,0896	0,7042	1
Al#3	0,0896	0,0376	0,2958	3
Al#4	0,0901	0,0366	0,2889	4

Based on the rank number and considering the total working hours of the personnel, Al#1 is selected and the information of the repairment activities is illustrated in Table 81.

Table 81. Information about the time of maintenance activities at Test_case#1 Iteration#8.

Information	*c5*
Current time	08:41
Day of repairment	*d2*

Date of repayment	21/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.2 Test_case#2

At Test_case#2 we have to deal with the same faults as Test_case#1. The main difference is that we have changed the weights of criteria (Table 10).

4.2.1 Iteration#1

The alternatives of Iteration#1 as well as the assignment of the criteria for the individual routes of each alternative, before and after the conversion of the qualitative criteria into numerical values, are the same as Iteration#1 of Test_cast_case#1 and are presented in Table 14, Table 15 and Table 16, respectively. Moreover, the Decision matrix (Table 17) and the normalized decision matrix (Table 18) do not change. The only difference is observed at the weighted normalized matrix, due to the alternation of the weights, and is illustrated in Table 82. Since the weighted normalized matrix has changed the ideal and anti-ideal solution also change (Table 83). Additionally, the distances between the ideal and inti-ideal solution, the relative closeness as well as the rank number of each alternative are presented in Table 84.

Table 82. Weighted matrix (V) at Test_case#2 Iteration#1.

	z1	z2	z3	z4	z6	z7	z8	z9	z10	z11	z12	z13	z14	z15
Al#1	0,021	0,021	0,013	0,013	0,004	0,020	0,016	0,003	0,003	0,025	0,018	0,018	0,020	0,016
Al#2	0,021	0,021	0,013	0,013	0,004	0,020	0,016	0,011	0,003	0,025	0,018	0,018	0,020	0,016
Al#3	0,002	0,002	0,013	0,013	0,004	0,020	0,019	0,025	0,023	0,003	0,018	0,018	0,020	0,018
Al#4	0,002	0,002	0,013	0,013	0,004	0,020	0,019	0,025	0,023	0,025	0,018	0,018	0,020	0,018
Al#5	0,021	0,021	0,013	0,013	0,004	0,020	0,025	0,003	0,003	0,003	0,018	0,018	0,020	0,020
Al#6	0,021	0,021	0,013	0,013	0,004	0,020	0,025	0,011	0,003	0,003	0,018	0,018	0,020	0,020
Al#7	0,002	0,002	0,013	0,013	0,004	0,015	0,016	0,025	0,023	0,025	0,018	0,018	0,020	0,016
Al#8	0,002	0,002	0,013	0,013	0,004	0,015	0,019	0,025	0,023	0,025	0,018	0,018	0,020	0,018
Al#9	0,002	0,002	0,013	0,013	0,004	0,015	0,016	0,025	0,023	0,025	0,018	0,018	0,020	0,016
Al#10	0,002	0,002	0,013	0,013	0,004	0,015	0,019	0,025	0,023	0,003	0,018	0,018	0,020	0,018
Al#11	0,021	0,021	0,013	0,013	0,004	0,012	0,016	0,003	0,003	0,025	0,018	0,018	0,020	0,016
Al#12	0,021	0,021	0,013	0,013	0,004	0,012	0,016	0,011	0,003	0,025	0,018	0,018	0,020	0,016
Al#13	0,002	0,002	0,013	0,013	0,004	0,015	0,019	0,025	0,023	0,003	0,018	0,018	0,020	0,018
Al#14	0,002	0,002	0,013	0,013	0,004	0,015	0,025	0,025	0,023	0,003	0,018	0,018	0,020	0,020
Al#15	0,002	0,002	0,013	0,013	0,004	0,012	0,019	0,025	0,023	0,003	0,018	0,018	0,020	0,018
Al#16	0,002	0,002	0,013	0,013	0,004	0,015	0,019	0,025	0,023	0,025	0,018	0,018	0,020	0,018
Al#17	0,002	0,002	0,013	0,013	0,004	0,015	0,025	0,025	0,023	0,003	0,018	0,018	0,020	0,020
Al#18	0,002	0,002	0,013	0,013	0,004	0,012	0,019	0,025	0,023	0,025	0,018	0,018	0,020	0,018
Al#19	0,021	0,021	0,013	0,013	0,004	0,012	0,025	0,003	0,003	0,003	0,018	0,018	0,020	0,020

Al#20	0,021	0,021	0,013	0,013	0,004	0,012	0,025	0,011	0,003	0,003	0,018	0,018	0,020	0,020

Table 83. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#2 Iteration#1.

Criterion code	A^+	A^-
z1	0,0210	0,0023
z2	0,0210	0,0023
z3	0,0134	0,0134
z4	0,0134	0,0134
z5	0,0045	0,0045
z6	0,0195	0,0122
z7	0,0251	0,0157
z8	0,0251	0,0028
z8	0,0230	0,0026
z10	0,0251	0,0028
z11	0,0179	0,0179
z12	0,0179	0,0179
z13	0,0201	0,0201
z14	0,0200	0,0156

Table 84. Ranking of maintenance plans at Test_case#2 Iteration#1.

Alternatives Code	d^+	d^-	RC	Rank
Al#1	0,0320	0,0354	0,5249	9
Al#2	0,0269	0,0364	0,5751	4
Al#3	0,0352	0,0314	0,4710	14
Al#4	0,0272	0,0385	0,5857	1
Al#5	0,0376	0,0293	0,4380	19
Al#6	0,0333	0,0305	0,4777	13
Al#7	0,0288	0,0377	0,5668	6
Al#8	0,0277	0,0379	0,5779	2
Al#9	0,0288	0,0377	0,5668	6
Al#10	0,0356	0,0306	0,4625	16
Al#11	0,0328	0,0346	0,5131	10
Al#12	0,0278	0,0356	0,5612	8
Al#13	0,0356	0,0306	0,4625	16
Al#14	0,0350	0,0321	0,4788	11

Al#15	0,0360	0,0305	0,4588	18
Al#16	0,0277	0,0379	0,5779	2
Al#17	0,0350	0,0321	0,4788	11
Al#18	0,0282	0,0378	0,5727	5
Al#19	0,0383	0,0284	0,4256	20
Al#20	0,0341	0,0296	0,4644	15

Compared to the rank number of Test_case#1 (Table 20) the rank numbers of the alternatives have changed. Specifically, based on the rank of the alternatives (Table 84) and considering that Al#4 is selected, meaning that team *p*2 will visit first the system *c6* the current day, i.e., *d*1, and then next day, i.e., *d*2, will repair system *c*5. In contrast to Iteration#1 of Test_case#1, at the current iteration of Test_case#2 the repairment of the systems are prioritized in order to minimize the time between the detection and the repairment. The information about the time of the maintenance activities is presented in Table 85.

Table 85. Information about the time instants of maintenance activities at Test_case#2 Iteration#1.

Information	*c*5	*c*6
Current time	17:23	17:23
Detection time	17:23	17:23
Day of repairment	*d*2	*d*1
Selected team	*p*2	*p*2
Start time of the trip	00:00	17:23
Traveling time (min)	0	41
Repairment time	8	5
End of repairment	8:41	23:04

4.2.2 Iteration#2

At Iteration#2 two tickets open for systems *c*1 and *c*2, and the model is executed again at 18:49. Since the repairment of system *c*6 has been already started, the current location of *p*2 is at *c*6, which is taken into account for the alternative's formulation. Due to the high number of alternatives, for shake of simplicity we present only the ten best alternatives. Specifically, the detailed routes of each alternative are presented in Table 86.

Table 86. Alternatives at Test_Case#2 Iteration#2.

Alternative No.	Team	Day	Route
Al#25	*p*1	*d*2	*c*7->*c*5
	*p*2	*d*2	*c*7->*c*1
	*p*2	*d*2	*c*1->*c*2
Al#26	*p*1	*d*2	*c*7->*c*5

	p2	*d2*	*c7->c2*
	p2	*d2*	*c2->c1*
AI#47	*p1*	*d2*	*c7->c1*
	p1	*d2*	*c1->c2*
	p2	*d2*	*c7->c5*
AI#53	*p1*	*d2*	*c7->c2*
	p1	*d2*	*c2->c1*
	p2	*d2*	*c7->c5*
AI#32	*p1*	*d2*	*c7->c1*
	p2	*d2*	*c7->c2*
	p2	*d2*	*c2->c5*
AI#38	*p1*	*d2*	*c7->c2*
	p2	*d2*	*c7->c1*
	p2	*d2*	*c1->c5*
AI#50	*p1*	*d2*	*c7->c1*
	p1	*d2*	*c1->c5*
	p2	*d2*	*c7->c2*
AI#51	*p1*	*d2*	*c7->c2*
	p1	*d2*	*c2->c5*
	p2	*d2*	*c7->c1*
AI#61	*p1*	*d1*	*c7->c5*
	p2	*d2*	*c7->c1*
	p2	*d2*	*c1->c2*
AI#62	*p1*	*d1*	*c7->c5*
	p2	*d2*	*c7->c2*
	p2	*d2*	*c2->c1*

At Table 87 and Table 88 the values of the criteria for the individual routes of the alternatives are demonstrated with a decent order of the rank number. Table 89, Table 90 and Table 91 illustrate the decision matrix, the normalized decision matrix and the weighted normalized decision matrix, respectively. Additionally, the ideal and anti-ideal solution of the criteria are presented in Table 92. Finally, Table 92 includes the distances of each alternative from the idea and anti-ideal solution, the relative closeness of each alternative as well as the rank numbers.

Table 87. Criteria and alternatives at Test_case#2 Iteration#2.

Team	Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#25	p1	d2	c7->c5	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	d2	c7->c1	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	d2	c1->c2	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
AI#26	p1	d2	c7->c5	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	d2	c2->c1	6,3	0	Asphalt	Medium	High	Expert	Medium	5,2	10,2	10,4	0	High	Marginal	Sunny
AI#47	p1	d2	c7->c1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p1	d2	c1->c2	0	0	Asphalt	Low	Medium	Competent	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
	p2	d2	c7->c5	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
AI#53	p1	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p1	d2	c2->c1	6,3	0	Asphalt	Medium	High	Competent	Medium	5,2	10,2	10,4	0	High	Marginal	Sunny
	p2	d2	c7->c5	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
AI#32	p1	d2	c7->c1	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	d2	c2->c5	26,4	39	Asphalt	High	High	Expert	Medium	5,2	13,85	13,85	0	High	Catastrophic	Cloudy
AI#38	p1	d2	c7->c2	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	d2	c7->c1	6,3	12	Asphalt	Medium	High	Expert	Medium	5,2	5,2	5,2	0	High	Marginal	Sunny
	p2	d2	c1->c5	26,4	39	Asphalt	High	High	Expert	Medium	0	13,85	13,85	0	High	Catastrophic	Cloudy

AI#50	*p1*	*d2*	*c7->c1*	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p1	*d2*	*c1->c5*	26,4	39	Asphalt	High	High	Competent	Medium	5,2	13,85	13,85	0	High	Catastrophic	Cloudy
	p2	*d2*	*c7->c2*	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
AI#51	*p1*	*d2*	*c7->c2*	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p1	*d2*	*c2->c5*	26,4	39	Asphalt	High	High	Competent	Medium	5,2	13,85	13,85	0	High	Catastrophic	Cloudy
	p2	*d2*	*c7->c1*	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
AI#61	*p1*	*d1*	*c7->c5*	27,3	41	Asphalt	High	High	Competent	Low	0	8,683	27,5	0	High	Catastrophic	Sunny
	p2	*d2*	*c7->c1*	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	*d2*	*c1->c2*	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
AI#25	*p1*	*d1*	*c7->c5*	27,3	41	Asphalt	High	High	Competent	Low	0	8,683	27,5	0	High	Catastrophic	Sunny
	p2	*d2*	*c7->c2*	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	*d2*	*c2->c1*	6,3	0	Asphalt	Medium	High	Expert	Medium	5,2	10,2	10,4	0	High	Marginal	Sunny

Table 88. Criteria and alternatives with numerical values at Test_case#2 Iteration#2.

Team	Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
Al#25	p1	d2	c7->c5	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p2	d2	c7->c1	6,3	12	8	5	8	8	5	0	5,2	5,2	0	8	4	9
	p2	d2	c1->c2	0	0	8	3	5	8	5	5,2	10,2	10,2	0	8	4	9
				33,6	53	8	5	7	7	5	5,2	10,2	0	0	8	5	8
Al#26	p1	d2	c7->c5	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8	7
	p2	d2	c7->c2	6,3	12	8	3	5	8	5	0	5,2	5,2	0	8	4	9
	p2	d2	c2->c1	6,3	0	8	5	8	8	5	5,2	10,2	10,4	0	8	4	9
				33,6	53	8	5	7	7	5	5,2	10,2	0	0	8	5	8
Al#47	p1	d2	c7->c1	6,3	12	8	5	8	5	5	0	5,2	5,2	0	8	4	9
	p1	d2	c1->c2	0	0	8	3	5	5	5	5,2	10,2	10,2	0	8	4	9
	p2	d2	c7->c5	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
				33,6	53	8	5	7	6	5	5,2	10,2	0	0	8	5	8
Al#53	p1	d2	c7->c2	6,3	12	8	3	5	5	5	0	5,2	5,2	0	8	4	9
	p1	d2	c2->c1	6,3	0	8	5	8	5	5	5,2	10,2	10,4	0	8	4	9
	p2	d2	c7->c5	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8	7
				33,6	53	8	5	7	6	5	5,2	10,2	0	0	8	5	8
Al#32	p1	d2	c7->c1	6,3	12	8	5	8	5	5	0	5,2	5,2	0	8	4	9
	p2	d2	c7->c2	6,3	12	8	3	5	8	5	0	5,2	5,2	0	8	4	9
	p2	d2	c2->c5	26,4	39	8	8	8	8	5	5,2	13,85	13,85	0	8	8	7
				39	63	8	5	7	7	5	5,2	13,85	0	0	8	5	8
Al#38	p1	d2	c7->c2	6,3	12	8	3	5	5	5	0	5,2	5,2	0	8	4	9
	p2	d2	c7->c1	6,3	12	8	5	8	8	5	0	5,2	5,2	0	8	4	9
	p2	d2	c1->c5	26,4	39	8	8	8	8	5	5,2	13,85	13,85	0	8	8	7
				39	63	8	5	7	7	5	5,2	13,85	0	0	8	5	8
Al#50	p1	d2	c7->c1	6,3	12	8	5	8	5	5	0	5,2	5,2	0	8	4	9
	p1	d2	c1->c5	26,4	39	8	8	8	5	5	5,2	13,85	13,85	0	8	8	7
	p2	d2	c7->c2	6,3	12	8	3	5	8	5	0	5,2	5,2	0	8	4	9
				39	63	8	5	7	6	5	5,2	13,85	0	0	8	5	8
Al#51	p1	d2	c7->c2	6,3	12	8	3	5	5	5	0	5,2	5,2	0	8	4	9
	p1	d2	c2->c5	26,4	39	8	8	8	5	5	5,2	13,85	13,85	0	8	8	7
	p2	d2	c7->c1	6,3	12	8	5	8	8	5	0	5,2	5,2	0	8	4	9
				39	63	8	5	7	6	5	5,2	13,85	0	0	8	5	8
Al#61	p1	d1	c7->c5	27,3	41	8	8	8	5	8	0	8,683	27,5	0	8	8	9
	p2	d2	c7->c1	6,3	12	8	5	8	8	5	0	5,2	5,2	0	8	4	9
	p2	d2	c1->c2	0	0	8	3	5	8	5	5,2	10,2	10,2	0	8	4	9
				33,6	53	8	5	7	7	6	5,2	10,2	1	0	8	5	9
Al#25	p1	d1	c7->c5	27,3	41	8	8	8	5	8	0	8,6833	27,5	0	8	8	9
	p2	d2	c7->c2	6,3	12	8	3	5	8	5	0	5,2	5,2	0	8	4	9
	p2	d2	c2->c1	6,3	0	8	5	8	8	5	5,2	10,2	10,4	0	8	4	9
				33,6	53	8	5	7	7	6	5,2	10,2	1	0	8	5	9

Table 89. Decision matrix (X) at Test_case#2 Iteration#2.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#25	6	6	8	5	7	7	5	8	9	9	9	8	5	8
AI#26	6	6	8	5	7	7	5	8	9	9	9	8	5	8
AI#47	6	6	8	5	7	6	5	8	9	9	9	8	5	8
AI#53	6	6	8	5	7	6	5	8	9	9	9	8	5	8
AI#32	6	5	8	5	7	7	5	8	1	9	9	8	5	8
AI#38	6	5	8	5	7	7	5	8	1	9	9	8	5	8
AI#50	6	5	8	5	7	6	5	8	1	9	9	8	5	8
AI#51	6	5	8	5	7	6	5	8	1	9	9	8	5	8
AI#61	6	6	8	5	7	7	6	8	9	1	9	8	5	9
AI#62	6	6	8	5	7	7	6	8	9	1	9	8	5	9

Table 90. Normalized decision matrix (R) at Test_case#2 Iteration#2.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#25	0,107	0,112	0,091	0,091	0,091	0,097	0,069	0,107	0,187	0,199	0,091	0,091	0,091	0,091
AI#26	0,107	0,112	0,091	0,091	0,091	0,097	0,069	0,107	0,187	0,199	0,091	0,091	0,091	0,091
AI#47	0,107	0,112	0,091	0,091	0,091	0,083	0,069	0,107	0,187	0,199	0,091	0,091	0,091	0,091
AI#53	0,107	0,112	0,091	0,091	0,091	0,083	0,069	0,107	0,187	0,199	0,091	0,091	0,091	0,091
AI#32	0,107	0,093	0,091	0,091	0,091	0,097	0,069	0,107	0,021	0,199	0,091	0,091	0,091	0,091
AI#38	0,107	0,093	0,091	0,091	0,091	0,097	0,069	0,107	0,021	0,199	0,091	0,091	0,091	0,091
AI#50	0,107	0,093	0,091	0,091	0,091	0,083	0,069	0,107	0,021	0,199	0,091	0,091	0,091	0,091
AI#51	0,107	0,093	0,091	0,091	0,091	0,083	0,069	0,107	0,021	0,199	0,091	0,091	0,091	0,091
AI#61	0,107	0,112	0,091	0,091	0,091	0,097	0,083	0,107	0,187	0,022	0,091	0,091	0,091	0,103
AI#62	0,107	0,112	0,091	0,091	0,091	0,097	0,083	0,107	0,187	0,022	0,091	0,091	0,091	0,103

Table 91. Weighted matrix (V) at Test_case#2 Iteration#2.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#25	0,006	0,007	0,005	0,005	0,002	0,007	0,006	0,010	0,015	0,016	0,007	0,007	0,008	0,007
AI#26	0,006	0,007	0,005	0,005	0,002	0,007	0,006	0,010	0,015	0,016	0,007	0,007	0,008	0,007
AI#47	0,006	0,007	0,005	0,005	0,002	0,006	0,006	0,010	0,015	0,016	0,007	0,007	0,008	0,007
AI#53	0,006	0,007	0,005	0,005	0,002	0,006	0,006	0,010	0,015	0,016	0,007	0,007	0,008	0,007
AI#32	0,006	0,006	0,005	0,005	0,002	0,007	0,006	0,010	0,002	0,016	0,007	0,007	0,008	0,007
AI#38	0,006	0,006	0,005	0,005	0,002	0,007	0,006	0,010	0,002	0,016	0,007	0,007	0,008	0,007
AI#50	0,006	0,006	0,005	0,005	0,002	0,006	0,006	0,010	0,002	0,016	0,007	0,007	0,008	0,007
AI#51	0,006	0,006	0,005	0,005	0,002	0,006	0,006	0,010	0,002	0,016	0,007	0,007	0,008	0,007
AI#61	0,006	0,007	0,005	0,005	0,002	0,007	0,007	0,010	0,015	0,002	0,007	0,007	0,008	0,008
AI#62	0,006	0,007	0,005	0,005	0,002	0,007	0,007	0,010	0,015	0,002	0,007	0,007	0,008	0,008

Table 92. Ideal (A^{+}) and the anti-ideal (A^{-}) solutions at Test_case#2 Iteration#2.

Criterion code	A^{+}	A^{-}
z1	0,0097	0,0011
z2	0,0100	0,0011
z3	0,0055	0,0055
z4	0,0055	0,0055
z5	0,0018	0,0018
z6	0,0078	0,0049
z7	0,0100	0,0062
z8	0,0108	0,0012
z8	0,0150	0,0017
z10	0,0159	0,0018
z11	0,0073	0,0073
z12	0,0073	0,0073
z13	0,0082	0,0082
z14	0,0082	0,0064

Table 93. Ranking of maintenance plans at Test_case#2 Iteration#2.

Alternatives Code	d^{+}	d^{-}	RC	Rank
Al#25	0,0062	0,0226	0,7842	1
Al#26	0,0062	0,0226	0,7842	1
Al#47	0,0065	0,0226	0,7777	3
Al#53	0,0065	0,0226	0,7777	3
Al#32	0,0150	0,0180	0,5461	5
Al#38	0,0150	0,0180	0,5461	5
Al#50	0,0151	0,0179	0,5434	7
Al#51	0,0151	0,0179	0,5434	7
Al#61	0,0152	0,0178	0,5391	9
Al#62	0,0152	0,0178	0,5391	9

From Table 87, Table 88 and Table 92 it is obvious that:

- The rank number of the three optimal alternatives, i.e., Al#25, Al#26 and Al#47, are mainly affected by the level of personnel expertise (z6).

- The working hours of personnel (z9) is a key factor for the estimation of the rank number.
- Although the total value of the 'Urgency' criterion (z7) at Al#61 is greater than the value at Al#25, the repairment of the system, the repairment of system *c*5 at Al#61 (11) is completed the next day *d*2, which significantly affects the rank number.

Based on the rank number of the alternatives, we select Al#25. The only difference between the selected alternative and Al#26 is the order systems *c*1 and *c*2 are repaired, which does not influence the rank number since they have the same level of fault severity and are cited at the same location.

Table 94. Information about the time of maintenance activities at Test_case#2 Iteration#2.

Information	*c*1	*c*2	*c*5
Current time	18:49	18:49	18:49
Detection time	18:49	18:49	17:23
Day of repairment	*d*2	*d*2	*d*2
Selected team	*p*2	*p*2	*p*1
Start time of the trip	00:00	5:12	0
Traveling time (min)	12	0	0
Repairment time	5	5	8
End of repairment	5:12	10:12	08:41

4.2.3 Iteration#3

The model is executed again at 15/05/2020 19:18 in order to handle the new ticket for system *c*6. The time the model is executed team *p*2 repair the previous fault occurred at the same system.

The ten best alternatives are presented in Table 95. Additionally, the detailed information of the criteria of the individual routes are presented in Table 96 and Table 97. Based on Table 97 it is clear that there are no differences between the summary of the criteria at Al#248, Al#262, Al#263 and Al#293. The only differences are observed at the personnel selection for the maintenance activities and at the repairment order of the systems located in *c*1 and *c*2.

Table 95. Alternatives at Test_Case#2 Iteration#3.

Alternative No.	Team	Day	Route
Al#248	*p*1	*d*2	*c*7->*c*1
	*p*1	*d*2	*c*1->*c*2
	*p*2	*d*2	*c*7->*c*6
	*p*2	*d*2	*c*6->*c*5
Al#262	*p*1	*d*2	*c*7->*c*6
	*p*1	*d*2	*c*6->*c*5
	*p*2	*d*2	*c*7->*c*1
	*p*2	*d*2	*c*1->*c*2
Al#263	*p*1	*d*2	*c*7->*c*6

	*p*1	*d*2	*c*6->*c*5
	*p*2	*d*2	*c*7->*c*2
	*p*2	*d*2	*c*2->*c*1
AI#293	*p*1	*d*2	*c*7->*c*2
	*p*1	*d*2	*c*2->*c*1
	*p*2	*d*2	*c*7->*c*6
	*p*2	*d*2	*c*6->*c*5
AI#217	*p*1	*d*2	*c*7->*c*5
	*p*1	*d*2	*c*5->*c*6
	*p*2	*d*2	*c*7->*c*1
	*p*2	*d*2	*c*1->*c*2
AI#218	*p*1	*d*2	*c*7->*c*5
	*p*1	*d*2	*c*5->*c*6
	*p*2	*d*2	*c*7->*c*2
	*p*2	*d*2	*c*2->*c*1
AI#247	*p*1	*d*2	*c*7->*c*1
	*p*1	*d*2	*c*1->*c*2
	*p*2	*d*2	*c*7->*c*5
	*p*2	*d*2	*c*5->*c*6
AI#292	*p*1	*d*2	*c*7->*c*2
	*p*1	*d*2	*c*2->*c*1
	*p*2	*d*2	*c*7->*c*5
	*p*2	*d*2	*c*5->*c*6
AI#445	*p*1	*d*1	*c*7->*c*6
	*p*1	*d*2	*c*7->*c*5
	*p*2	*d*2	*c*7->*c*1
	*p*2	*d*2	*c*1->*c*2
AI#446	*p*1	*d*1	*c*7->*c*5
	*p*1	*d*2	*c*7->*c*6
	*p*2	*d*2	*c*7->*c*2
	*p*2	*d*2	*c*2->*c*1

Table 98, Table 99 and Table 100 represent the decision matrix, the normalized decision matrix and the weighted normalized decision matrix, respectively. Additionally, the ideal and anti-idea solutions are included in Table 101. Finally, the rank number of the alternatives as well as their distances from the ideal and anti-ideal solutions are demonstrated in Table 102. Considering the rank number of the alternatives it is clear that the alternatives with the minimum time of personnel unavailability (z8) and the minimum working hours of the personnel (z9) are more favorable.

Table 96. Criteria and alternatives at Test_case#2 Iteration#3.

	Team	Day	Route		z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#248	*p*1	*d*2	*c*7->*c*1	*5*	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	*p*1	*d*2	*c*1->*c*2	*5*	0	0	Asphalt	Low	Medium	Competent	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
	*p*2	*d*2	*c*7->*c*6	*2*	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	2,683	2,683	0	High	Negligible	Cloudy
	*p*2	*d*2	*c*6->*c*5	*8*	0	0	Asphalt	High	High	Expert	Medium	2,683	10,683	10,683	0	High	Catastrophic	Cloudy
AI#262	*p*1	*d*2	*c*7->*c*6	*2*	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	2,683	2,683	0	High	Negligible	Cloudy
	*p*1	*d*2	*c*6->*c*5	*8*	0	0	Asphalt	High	High	Competent	Medium	2,683	10,683	10,683	0	High	Catastrophic	Cloudy
	*p*2	*d*2	*c*7->*c*1	*5*	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	*p*2	*d*2	*c*1->*c*2	*5*	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
AI#263	*p*1	*d*2	*c*7->*c*6	*2*	27,3	41	Asphalt	Medium	Medium	Competent	Medium	0	2,683	2,683	0	High	Negligible	Cloudy
	*p*1	*d*2	*c*6->*c*5	*8*	0	0	Asphalt	High	High	Competent	Medium	2,683	10,683	10,683	0	High	Catastrophic	Cloudy
	*p*2	*d*2	*c*7->*c*2	*5*	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	*p*2	*d*2	*c*2->*c*1	*5*	0	0	Asphalt	Medium	High	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
AI#292	*p*1	*d*2	*c*7->*c*2	*5*	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	*p*1	*d*2	*c*2->*c*1	*5*	0	0	Asphalt	Medium	High	Competent	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
	*p*2	*d*2	*c*7->*c*6	*2*	27,3	41	Asphalt	Medium	Medium	Expert	Medium	0	2,683	2,683	0	High	Negligible	Cloudy
	*p*2	*d*2	*c*6->*c*5	*8*	0	0	Asphalt	High	High	Expert	Medium	2,683	10,683	10,683	0	High	Catastrophic	Cloudy
AI#216	*p*1	*d*2	*c*7->*c*5	*8*	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	*p*1	*d*2	*c*5->*c*6	*2*	0	0	Asphalt	Medium	Medium	Competent	Medium	8,683	10,683	10,683	0	High	Negligible	Cloudy
	*p*2	*d*2	*c*7->*c*1	*5*	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	*p*2	*d*2	*c*1->*c*2	*5*	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny

AI#217	*p1*	*d2*	*c7->c5*	*8*	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p1	*d2*	*c5->c6*	*2*	0	0	Asphalt	Medium	Medium	Competent	Medium	8,683	10,683	10,683	0	High	Negligible	Cloudy
	p2	*d2*	*c7->c2*	*5*	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	*d2*	*c2->c1*	*5*	0	0	Asphalt	Medium	High	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
AI#247	*p1*	*d2*	*c7->c1*	*5*	6,3	12	Asphalt	Medium	High	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p1	*d2*	*c1->c2*	*5*	0	0	Asphalt	Low	Medium	Competent	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
	p2	*d2*	*c7->c5*	*8*	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	*d2*	*c5->c6*	*2*	0	0	Asphalt	Medium	Medium	Expert	Medium	8,683	10,683	10,683	0	High	Negligible	Cloudy
AI#292	*p1*	*d2*	*c7->c2*	*5*	6,3	12	Asphalt	Low	Medium	Competent	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p1	*d2*	*c2->c1*	*5*	0	0	Asphalt	Medium	High	Competent	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
	p2	*d2*	*c7->c5*	*8*	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Cloudy
	p2	*d2*	*c5->c6*	*2*	0	0	Asphalt	Medium	Medium	Expert	Medium	8,683	10,683	10,683	0	High	Negligible	Cloudy
AI#445	*p1*	*d1*	*c7->c5*	*8*	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Sunny
	p2	*d2*	*c6->c6*	*5*	27,3	41	Asphalt	Medium	Medium	Competent	Low	0	5,683	5,683	0	High	Negligible	Cloudy
	p2	*d2*	*c7->c1*	*5*	6,3	12	Asphalt	Medium	High	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	*d2*	*c1->c2*	*5*	0	0	Asphalt	Low	Medium	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny
AI#446	*p1*	*d1*	*c7->c5*	*8*	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Sunny
	p1	*d2*	*c7->c6*	*2*	27,3	41	Asphalt	Medium	Medium	Competent	Low	0	2,683	2,683	0	High	Negligible	Cloudy
	p2	*d2*	*c7->c2*	*5*	6,3	12	Asphalt	Low	Medium	Expert	Medium	0	5,2	5,2	0	High	Marginal	Sunny
	p2	*d2*	*c2->c1*	*5*	0	0	Asphalt	Medium	High	Expert	Medium	5,2	10,2	10,2	0	High	Marginal	Sunny

Table 97. Criteria and alternatives with numerical values at Test_case#2 Iteration#3.

	Team	Day	Route	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#248	p1	d2	c7->c1	5	6,3	12	8	5	8	5	5	0	5,2	5,2	0	8	4
	p1	d2	c1->c2	5	0	0	8	2	5	5	5	5,2	10,2	10,2	0	8	4
	p2	d2	c7->c6	2	27,3	41	8	5	5	8	5	0	2,683	2,683	0	8	2
	p2	d2	c6->c5	8	0	0	8	8	8	8	5	2,683	10,683	10,683	0	8	8
					33,6	53	8	5	6	6	5	7,883	10,683	0	0	8	4
AI#262	p1	d2	c7->c6	2	27,3	41	8	5	5	5	5	0	2,683	2,683	0	8	2
	p1	d2	c6->c5	8	0	0	8	8	8	5	5	2,683	10,683	10,683	0	8	8
	p2	d2	c7->c1	5	6,3	12	8	5	8	8	5	0	5,2	5,2	0	8	4
	p2	d2	c1->c2	5	0	0	8	2	5	8	5	5,2	10,2	10,2	0	8	4
					33,6	53	8	5	6	6	5	7,883	10,683	0	0	8	4
AI#263	p1	d2	c7->c6	2	27,3	41	8	5	5	5	5	0	2,683	2,683	0	8	2
	p1	d2	c6->c5	8	0	0	8	8	8	5	5	2,683	10,683	10,683	0	8	8
	p2	d2	c7->c2	5	6,3	12	8	2	5	8	5	0	5,2	5,2	0	8	4
	p2	d2	c2->c1	5	0	0	8	5	8	8	5	5,2	10,2	10,2	0	8	4
					33,6	53	8	5	6	6	5	7,883	10,683	0	0	8	4
AI#292	p1	d2	c7->c2	5	6,3	12	8	2	5	5	5	0	5,2	5,2	0	8	4
	p1	d2	c2->c1	5	0	0	8	5	8	5	5	5,2	10,2	10,2	0	8	4
	p2	d2	c7->c6	2	27,3	41	8	5	5	8	5	0	2,683	2,683	0	8	2
	p2	d2	c6->c5	8	0	0	8	8	8	8	5	2,683	10,683	10,683	0	8	8
					33,6	53	8	5	6	6	5	7,883	10,683	0	0	8	4
AI#216	p1	d2	c7->c5	8	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8
	p1	d2	c5->c6	2	0	0	8	5	5	5	5	8,683	10,683	10,683	0	8	2
	p2	d2	c7->c1	5	6,3	12	8	5	8	8	5	0	5,2	5,2	0	8	4
	p2	d2	c1->c2	5	0	0	8	2	5	8	5	5,2	10,2	10,2	0	8	4
					33,6	53	8	5	6	6	5	13,883	10,683	0	0	8	4
AI#217	p1	d2	c7->c5	8	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8
	p1	d2	c5->c6	2	0	0	8	5	5	5	5	8,683	10,683	10,683	0	8	2
	p2	d2	c7->c2	5	6,3	12	8	2	5	8	5	0	5,2	5,2	0	8	4
	p2	d2	c2->c1	5	0	0	8	5	8	8	5	5,2	10,2	10,2	0	8	4
					33,6	53	8	5	6	6	5	13,883	10,683	0	0	8	4
AI#247	p1	d2	c7->c1	5	6,3	12	8	5	8	5	5	0	5,2	5,2	0	8	4
	p1	d2	c1->c2	5	0	0	8	2	5	5	5	5,2	10,2	10,2	0	8	4
	p2	d2	c7->c5	8	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8
	p2	d2	c5->c6	2	0	0	8	5	5	8	5	8,683	10,683	10,683	0	8	2
					33,6	53	8	5	6	6	5	13,883	10,683	0	0	8	4
AI#292	p1	d2	c7->c2	5	6,3	12	8	2	5	5	5	0	5,2	5,2	0	8	4
	p1	d2	c2->c1	5	0	0	8	5	8	5	5	5,2	10,2	10,2	0	8	4
	p2	d2	c7->c5	8	27,3	41	8	8	8	8	5	0	8,683	8,683	0	8	8
	p2	d2	c5->c6	2	0	0	8	5	5	8	5	8,683	10,683	10,683	0	8	2
					33,6	53	8	5	6	6	5	13,883	10,683	0	0	8	4
AI#445	p1	d1	c7->c5	8	27,3	41	8	8	8	5	5	0	8,683	8,683	0	8	8

	p2	*d2*	*c6->c6*	*5*	27,3	41	8	5	5	*5*	8	0	5,683	5,683	0	8	2
	p2	*d2*	*c7->c1*	*5*	6,3	12	8	5	8	*8*	5	0	5,2	5,2	0	8	4
	p2	*d2*	*c1->c2*	*5*	0	0	8	2	5	*8*	5	5,2	10,2	10,2	0	8	4
					60,9	94	8	5	6	6	6	5,2	10,2	0	0	8	4
AI#446	*p1*	*d1*	*c7->c5*	*8*	27,3	41	8	8	8	*5*	5	0	8,683	8,683	0	8	8
	p1	*d2*	*c7->c6*	*2*	27,3	41	8	5	5	*5*	8	0	2,683	2,683	0	8	2
	p2	*d2*	*c7->c2*	*5*	6,3	12	8	2	5	*8*	5	0	5,2	5,2	0	8	4
	p2	*d2*	*c2->c1*	*5*	0	0	8	5	8	*8*	5	5,2	10,2	10,2	0	8	4
					60,9	94	8	5	6	6	6	5,2	10,2	0	0	8	4

Table 98. Decision matrix (X) at Test_case#2 Iteration#3.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#248	9	9	8	5	6	6	5	9	9	9	9	8	4	8
AI#262	9	9	8	5	6	6	5	9	9	9	9	8	4	8
AI#263	9	9	8	5	6	6	5	9	9	9	9	8	4	8
AI#292	9	9	8	5	6	6	5	9	9	9	9	8	4	8
AI#216	9	9	8	5	6	6	5	8	9	9	9	8	4	8
AI#217	9	9	8	5	6	6	5	8	9	9	9	8	4	8
AI#247	9	9	8	5	6	6	5	8	9	9	9	8	4	8
AI#292	9	9	8	5	6	6	5	8	9	9	9	8	4	8
AI#445	6	6	8	5	6	6	6	9	9	9	9	8	4	8
AI#446	6	6	8	5	6	6	6	9	9	9	9	8	4	8

Table 99. Normalized decision matrix (R) at Test_case#2 Iteration#3.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#248	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,042	0,083	0,081	0,035	0,035	0,035	0,034
AI#262	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,042	0,083	0,081	0,035	0,035	0,035	0,034
AI#263	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,042	0,083	0,081	0,035	0,035	0,035	0,034
AI#292	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,042	0,083	0,081	0,035	0,035	0,035	0,034
AI#216	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,038	0,083	0,081	0,035	0,035	0,035	0,034
AI#217	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,038	0,083	0,081	0,035	0,035	0,035	0,034
AI#247	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,038	0,083	0,081	0,035	0,035	0,035	0,034
AI#292	0,055	0,056	0,035	0,035	0,035	0,032	0,027	0,038	0,083	0,081	0,035	0,035	0,035	0,034
AI#445	0,037	0,037	0,035	0,035	0,035	0,032	0,032	0,042	0,083	0,081	0,035	0,035	0,035	0,034
AI#446	0,037	0,037	0,035	0,035	0,035	0,032	0,032	0,042	0,083	0,081	0,035	0,035	0,035	0,034

Table 100. Weighted matrix (V) at Test_case#2 Iteration#3.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#248	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,004	0,007	0,006	0,003	0,003	0,003	0,003
AI#262	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,004	0,007	0,006	0,003	0,003	0,003	0,003
AI#263	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,004	0,007	0,006	0,003	0,003	0,003	0,003

AI#292	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,004	0,007	0,006	0,003	0,003	0,003	0,003
AI#216	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,003	0,007	0,006	0,003	0,003	0,003	0,003
AI#217	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,003	0,007	0,006	0,003	0,003	0,003	0,003
AI#247	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,003	0,007	0,006	0,003	0,003	0,003	0,003
AI#292	0,003	0,003	0,002	0,002	0,001	0,002	0,002	0,003	0,007	0,006	0,003	0,003	0,003	0,003
AI#445	0,002	0,002	0,002	0,002	0,001	0,002	0,003	0,004	0,007	0,006	0,003	0,003	0,003	0,003
AI#446	0,002	0,002	0,002	0,002	0,001	0,002	0,003	0,004	0,007	0,006	0,003	0,003	0,003	0,003

Table 101. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#2 Iteration#3.

Criterion code	A^+	A^-
z1	0,0033	0,0004
z2	0,0034	0,0004
z3	0,0021	0,0021
z4	0,0021	0,0021
z5	0,0007	0,0007
z6	0,0030	0,0019
z7	0,0039	0,0024
z8	0,0038	0,0004
z8	0,0066	0,0007
z10	0,0065	0,0007
z11	0,0028	0,0028
z12	0,0028	0,0028
z13	0,0031	0,0031
z14	0,0031	0,0024

Table 102. Ranking of maintenance plans at Test_case#2 Iteration#3.

Alternatives Code	d^+	d^-	RC	Rank
AI#248	0,0017	0,0099	0,8554	1
AI#262	0,0017	0,0099	0,8554	1
AI#263	0,0017	0,0099	0,8554	1
AI#292	0,0017	0,0099	0,8554	1
AI#216	0,0017	0,0097	0,8496	5
AI#217	0,0017	0,0097	0,8496	5
AI#247	0,0017	0,0097	0,8496	5
AI#292	0,0017	0,0097	0,8496	5
AI#445	0,0020	0,0093	0,8216	9

AI#446	0,0020	0,0093	0,8216	9

Based on the rank number, at the present iteration we select AI#262. The detailed information about the maintenance activities is presented in Table 103.

Table 103. Information about the time of maintenance activities at Test_case#2 Iteration#3.

Information	*c*1	*c*2	*c*5	*c*6
Current time	19:18	19:18	19:18	19:18
Detection time	18:49	18:49	17:23	19:18
Day of repairment	*d*2	*d*2	*d*2	*d*2
Selected team	*p*2	*p*2	*p*1	*p*1
Start time of the trip	00:00	5:12	05:41	00:00
Traveling time (min)	12	0	0	41
Repairment time	5	5	8	2
End of repairment	5:12	10:12	10:41	02:41

4.2.4 Iteration#4

The concept of Iteration#4 at Tect_case#2 is the same as Iteration#4 at Test_case#1, meaning that systems *c*1, *c*2 and *c*6 have been repaired and we have to deal with the sub-maintenance activities of system *c*5. The alternatives and the criteria referring to the 'Urgency' and the 'Weather severity' are presented in Table 41 and Table 42, respectively. There are no differences between the alternatives as well as the criteria in terms of the repairment day at Iteraration#4 of Test_case#1 and Test_case#2, since we have the same fault to repair.

Considering that the current location of personnel *p*1 is *c*5, the detailed values of criteria for the alternative's individual routes are illustrated in Table 104 and Table 105. Table 106, Table 107 and Table 108 include the decision matrix, the normalized decision matrix and the weighted normalized decision matrix, respectively. The ideal and anti-ideal solutions of the criteria are presented in Table 109.

Table 104. Criteria and alternatives at Test_case#2 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	Asphalt	High	High	Competent	Medium	0	8,683	8,683	0	High	Catastrophic	Sunny
AI#2	0	0	Asphalt	High	High	Competent	High	0	18,883	18,883	0	High	Catastrophic	Cloudy
AI#3	27,3	41	Asphalt	High	High	Expert	Medium	0	8,683	8,683	0	High	Catastrophic	Sunny
AI#4	27,3	41	Asphalt	High	High	Expert	High	0	18,683	18,683	0	High	Catastrophic	Cloudy

Table 105. Criteria and alternatives with numerical values at Test_case#2 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	27,3	41	8	8	8	8	3	0	8,683	0	0	8	8	9
AI#2	27,3	41	8	8	8	8	5	0	18,883	0	0	8	8	7
AI#3	27,3	41	8	8	8	5	3	0	8,683	0	0	8	8	9
AI#4	0	0	8	8	8	5	5	0	18,683	0	0	8	8	7

Table 106. Decision matrix (X) at Test_case#2 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	1	1	8	8	8	8	3	9	9	9	9	8	8	9
AI#2	9	9	8	8	8	8	5	9	1	9	9	8	8	7
AI#3	1	1	8	8	8	5	3	9	9	9	9	8	8	9
AI#4	1	1	8	8	8	5	5	9	1	9	9	8	8	7

Table 107. Normalized decision matrix (R) at Test_case#2 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,109	0,109	0,500	0,500	0,500	0,600	0,364	0,500	0,703	0,500	0,500	0,500	0,500	0,558
AI#2	0,109	0,109	0,500	0,500	0,500	0,600	0,606	0,500	0,078	0,500	0,500	0,500	0,500	0,434
AI#3	0,109	0,109	0,500	0,500	0,500	0,375	0,364	0,500	0,703	0,500	0,500	0,500	0,500	0,558
AI#4	0,982	0,982	0,500	0,500	0,500	0,375	0,606	0,500	0,078	0,500	0,500	0,500	0,500	0,434

Table 108. Weighted matrix (V) at Test_case#2 Iteration#4.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,007	0,007	0,030	0,030	0,010	0,042	0,033	0,045	0,056	0,040	0,040	0,040	0,045	0,045
AI#2	0,007	0,007	0,030	0,030	0,010	0,042	0,055	0,045	0,006	0,040	0,040	0,040	0,045	0,035
AI#3	0,007	0,007	0,030	0,030	0,010	0,026	0,033	0,045	0,056	0,040	0,040	0,040	0,045	0,045
AI#4	0,059	0,059	0,030	0,030	0,010	0,026	0,055	0,045	0,006	0,040	0,040	0,040	0,045	0,035

Table 109. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#2 Iteration#4.

Criterion code	A^+	A^-
z1	0,0589	0,0065
z2	0,0589	0,0065
z3	0,0300	0,0300
z4	0,0300	0,0300
z5	0,0100	0,0100
z6	0,0420	0,0262
z7	0,0546	0,0327
z8	0,0450	0,0450

z8	0,0562	0,0062
z10	0,0400	0,0400
z11	0,0400	0,0400
z12	0,0400	0,0400
z13	0,0450	0,0450
z14	0,0447	0,0347

At Table 110 the rank number of the alternatives alongside with the distances between each alternative to the idea and anti-ideal solution and the relative closeness presented. Base on the rank number it is clear that Al#4, which is the alternative with the minimum travelling distance, has the best rank number. However, considering the working hours of the personnel we select AL#1 which indicates that team *p*2 will repair the system the next day, i.e., at 17/05/2020. The detailed description of the repairment is demonstrated in Table 111.

Table 110. Ranking of maintenance plans at Test_case#2 Iteration#4.

Alternatives Code	d^+	d^-	RC	**Rank**
Al#1	0,0772	0,0533	0,4085	2
Al#2	0,0899	0,0269	0,2304	4
Al#3	0,0788	0,0510	0,3927	3
Al#4	0,0533	0,0772	0,5915	1

Table 111. Information about the time of maintenance activities at Test_case#2 Iteration#4.

Information	***c5***
Current time	13:41
Day of repairment	*d*2
Date of repairment	17/05/2020
Selected team	*p*2
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.2.5 Iteration#5

At Iteration#5 of Test case#2 we have the same initial conditions as Test_case#1, meaning that the second sub-maintenance activity of system c6 is completed at 17/05/2020 08:41 by the second team (p2). So, there are no differences between the values of the criteria (Table 52 and Table 53), the decision matrix (Table 54) and the normalized decision matrix (Table 55) of the two test cases. The only difference is observed at the weighted normalized matrix, which is presented in Table 112, and the ideal and anti-ideal solution of each criterion, which is demonstrated in Table 113. This is expected due to the different weights we have set for each criterion.

Apart from the different weighs, comparing the alternatives' rank number of Iteration#5 of Test_case#1 (Table 58) and Test_case#2 (Table 114) no differences are observed. The model proposes as best alternative AI#2, considering the minimum travelling distance, without taking into account the high value of the working hours, while the second best alternative is based on the expertise of the personnel.

Table 112. Weighted matrix (V) at Test_case#2 Iteration#5.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,007	0,007	0,030	0,030	0,010	0,042	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,040
AI#2	0,059	0,059	0,030	0,030	0,010	0,042	0,045	0,045	0,005	0,040	0,040	0,040	0,045	0,040
AI#3	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,040
AI#4	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,040

Table 113. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#2 Iteration#5.

Criterion code	A^+	A^-
z1	0,0589	0,0065
z2	0,0589	0,0065
z3	0,0300	0,0300
z4	0,0300	0,0300
z5	0,0100	0,0100
z6	0,0420	0,0262
z7	0,0450	0,0450
z8	0,0450	0,0450
z8	0,0461	0,0051
z10	0,0400	0,0400
z11	0,0400	0,0400
z12	0,0400	0,0400
z13	0,0450	0,0450
z14	0,0400	0,0400

Table 114. Ranking of maintenance plans at Test_case#2 Iteration#5.

Alternatives Code	d^+	d^-	RC	Rank
AI#1	0,0741	0,0439	0,3721	2
AI#2	0,0410	0,0757	0,6489	1

AI#3	0,0757	0,0410	0,3511	3
AI#4	0,0757	0,0410	0,3511	3

Based on the rank number of the alternatives and considering the working hours of the personnel we select AI#1, meaning that the second team will continue the maintenance activities the next day. The details about the maintenance activities are included in Table 115

Table 115. Information about the time of maintenance activities at Test_case#2 Iteration#5.

Information	***c5***
Current time	08:41
Day of repairment	*d2*
Date of repayment	18/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.2.6 Iteration#6

At Iteration#6 of Test_case#2 we have to deal the third sub-maintenance activity of system *c*5, as Iteration#6 of Test_case#1. The alternatives, the values of the criteria before and after the conversion of qualitative criteria, the decision matrix and the normalized decision matrix are the same as Iteration#6 of Test_case#1. The weighted normalized matrix and the ideal and anti-ideal solutions of the criteria are presented in Table 116 and 117 respectively.

Table 116. Weighted matrix (V) at Test_case#2 Iteration#6.

	z1	**z2**	**z3**	**z4**	**z5**	**z6**	**z7**	**z8**	**z9**	**z10**	**z11**	**z12**	**z13**	**z14**
AI#1	0,007	0,007	0,030	0,030	0,010	0,042	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,040
AI#2	0,059	0,059	0,030	0,030	0,010	0,042	0,045	0,045	0,005	0,040	0,040	0,040	0,045	0,040
AI#3	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,040
AI#4	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,040

Table 117. Ideal (A^{+}) and the anti-ideal (A^{-}) solutions at Test_case#2 Iteration#6.

Criterion code	A^{+}	A^{-}
z1	0,0589	0,0065
z2	0,0589	0,0065
z3	0,0300	0,0300
z4	0,0300	0,0300

z5	0,0100	0,0100
z6	0,0420	0,0262
z7	0,0450	0,0450
z8	0,0450	0,0450
z8	0,0461	0,0051
z10	0,0400	0,0400
z11	0,0400	0,0400
z12	0,0400	0,0400
z13	0,0450	0,0450
z14	0,0400	0,0400

Table 118. Ranking of maintenance plans at Test_case#2 Iteration#6.

Alternatives Code	d^{+}	d^{-}	RC	**Rank**
Al#1	0,0741	0,0439	0,3721	2
Al#2	0,0410	0,0757	0,6489	1
Al#3	0,0757	0,0410	0,3511	3
Al#4	0,0757	0,0410	0,3511	3

The rank number of the alternatives are included in Table 118, and are the same as the previous iteration, i.e., Iteration#5. This is expected since the weather conditions, the location of the personnel and the severity of fault are the same. Based on the rank number of the alternatives and considering the working hours of the personnel we select Al#1, meaning that the second team will continue the maintenance activities the next day. The details about the maintenance activities are included in Table 119

Table 119. Information about the time of maintenance activities at Test_case#2 Iteration#6.

Information	***c5***
Current time	08:41
Day of repairment	*d2*
Date of repayment	19/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.2.7 Iteration#7

The conditions of the current iteration, such as the forecasted PV power and the weather conditions have been explicitly described in section 4.1.7 (Iteration#7 Test_case#1). Additionally, the values of the criteria for each alternative before and after the conversion of the qualitative criteria into ranged values are presented remains the same as Iteration#7 of Test_case#1 and are presented in Table 65 and Table 66. The decision matrix (Table 67) and the normalized decision matrix (Table 68) remain the same as well. The only differences are observed in the weighted normalized decision matrix and the ideal and inti-ideal solution and are demonstrated in Table 120 and table 121, respectively.

Table 120. Weighted matrix (V) at Test_case#2 Iteration#7.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
Al#1	0,007	0,007	0,030	0,030	0,010	0,042	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,035
Al#2	0,059	0,059	0,030	0,030	0,010	0,042	0,045	0,045	0,005	0,040	0,040	0,040	0,045	0,045
Al#3	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,035
Al#4	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,045

Table 121. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#2 Iteration#7.

Criterion code	A^+	A^-
z1	0,0589	0,0065
z2	0,0589	0,0065
z3	0,0300	0,0300
z4	0,0300	0,0300
z5	0,0100	0,0100
z6	0,0420	0,0262
z7	0,0450	0,0450
z8	0,0450	0,0450
z8	0,0461	0,0051
z10	0,0400	0,0400
z11	0,0400	0,0400
z12	0,0400	0,0400
z13	0,0450	0,0450
z14	0,0447	0,0347

From the rank number of the alternatives, that are presented in Table 122, it is clear that the rank number between Al#3 and Al#4 is affected by the weather conditions. Specifically, Al#4, according to which the repairment is assigned to team *p*1 for the current day with sunny weather, has lower rank number than Al#3, which indicates that team *p*2 will visit the system the next day with cloudy weather. This was also clear at Iteration#7 of Test_case#1. However, since the ranged values of the weather conditions are not dramatically different the level of personnel expertise is the criterion which mainly affects the rank number of the total alternatives.

Table 122. Ranking of maintenance plans at Test_case#2 Iteration#7.

Alternatives Code	d^+	d^-	RC	Rank
AI#1	0,0747	0,0439	0,3700	2
AI#2	0,0410	0,0764	0,6508	1
AI#3	0,0764	0,0410	0,3492	4
AI#4	0,0757	0,0422	0,3576	3

AI#1 is selected for once more considering the rank number and the daily working hours of the personnel. The details of the maintenance activities are presented in Table 123.

Table 123. Information about the time of maintenance activities at Test_case#2 Iteration#7.

Information	*c5*
Current time	08:41
Day of repairment	*d2*
Date of repayment	20/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41
Repairment time	8
End of repairment	08:41

4.2.8 Iteration#8

The initial conditions of Iteration#8 of Test_case#2 are the same as Iteration#8 of Test_case#1 and are described in section 4.1.8. The main differences lie again at the weighted matrix and the ideal and anti-ideal solution which are presented in Table 124 and Table 125, respectively.

Table 124. Weighted matrix (V) at Test_case#2 Iteration#8.

	z1	z2	z3	z4	z5	z6	z7	z8	z9	z10	z11	z12	z13	z14
AI#1	0,007	0,007	0,030	0,030	0,010	0,042	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,045
AI#2	0,059	0,059	0,030	0,030	0,010	0,042	0,045	0,045	0,005	0,040	0,040	0,040	0,045	0,035
AI#3	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,045
AI#4	0,007	0,007	0,030	0,030	0,010	0,026	0,045	0,045	0,046	0,040	0,040	0,040	0,045	0,035

Table 125. Ideal (A^+) and the anti-ideal (A^-) solutions at Test_case#2 Iteration#8.

Criterion code	A^+	A^-

z1	0,0589	0,0065
z2	0,0589	0,0065
z3	0,0300	0,0300
z4	0,0300	0,0300
z5	0,0100	0,0100
z6	0,0420	0,0262
z7	0,0450	0,0450
z8	0,0450	0,0450
z8	0,0461	0,0051
z10	0,0400	0,0400
z11	0,0400	0,0400
z12	0,0400	0,0400
z13	0,0450	0,0450
z14	0,0447	0,0347

At the current iteration the rank number of the alternatives are included in Table 126. It is clear that the rank number is affected by the expertise of the personnel and the weather conditions. The same conclusion derived from the previous iteration as well.

Table 126. Ranking of maintenance plans at Test_case#2 Iteration#8.

Alternatives Code	d^{+}	d^{-}	RC	Rank
Al#1	0,0741	0,0450	0,3779	2
Al#2	0,0422	0,0757	0,6424	1
Al#3	0,0757	0,0422	0,3576	3
Al#4	0,0764	0,0410	0,3492	4

Considering the rank number and the daily working hours of the personnel, Al#1 is selected. Table 127 includes the details of the maintenance activities.

Table 127. Information about the time of maintenance activities at Test_case#2 Iteration#8.

Information	*c5*
Current time	08:41
Day of repairment	*d2*
Date of repayment	21/05/2020
Selected team	*p2*
Start time of the trip	00:00
Traveling time (min)	41

Repairment time	8
End of repairment	08:41

4.3 Comparison of test cases

From the examined test cases the assignment of different weights can lead to different optimal alternatives. This is obvious at the first execution of the model. Specifically, at Test_case#1 the maintenance activities are prioritized considering the minimum distance and travelling time, while in Test_case#2 the maintenance activities are prioritized in order to minimize the time between the detection and the repairment time. Figure 4 depicts the selected best alternatives of Test_case#1 and Test_case#2 at Iteration#1. The maintenance activities of the examined test cases are presented in Figure 5. For sake of simplicity, Iterarion#4, Iteration#6, Iteration#7 and Iteration#8 are excluded since they are the same for both test cases.

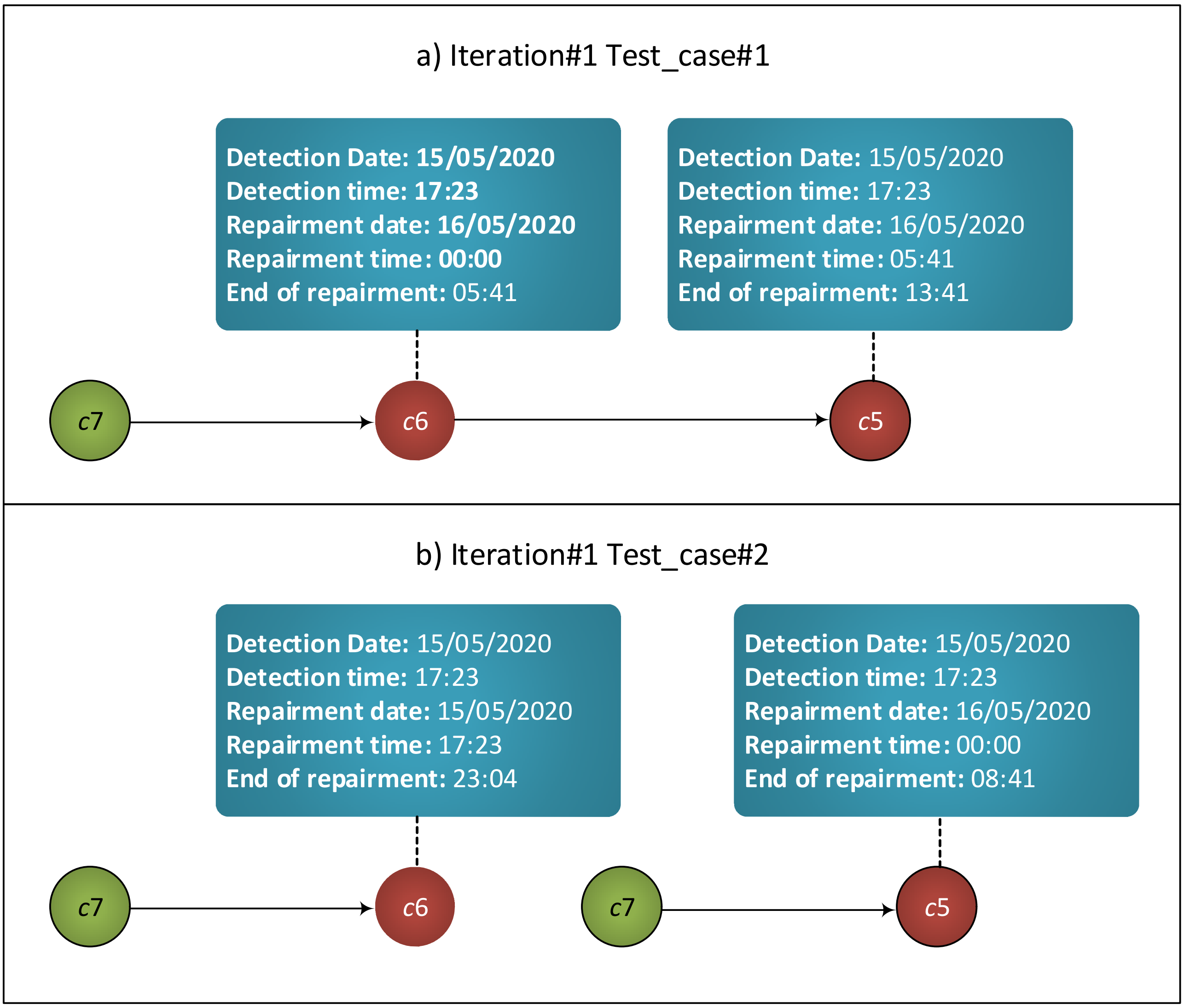

Figure 4. Best alternatives of Iteration#1: a) Test_case#1 and b) Test_case#2.

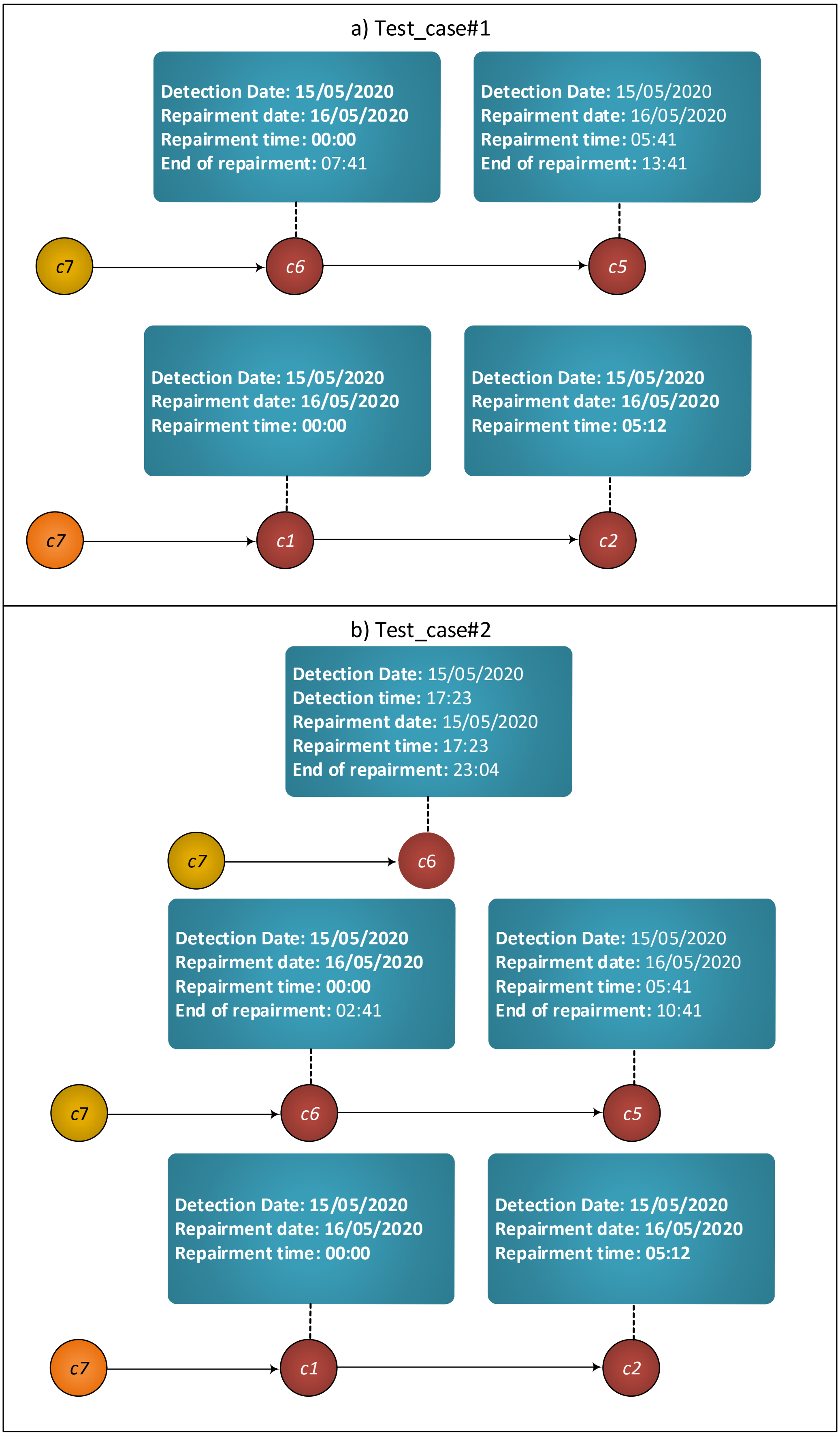
a) Test_case#1
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 00:00
End of repairment: 07:41
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 05:41
End of repairment: 13:41
c7
c6
c5
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 00:00
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 05:12
c7
c1
c2
b) Test_case#2
Detection Date: 15/05/2020
Detection time: 17:23
Repairment date: 15/05/2020
Repairment time: 17:23
End of repairment: 23:04
c7
c6
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 00:00
End of repairment: 02:41
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 05:41
End of repairment: 10:41
c7
c6
c5
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 00:00
Detection Date: 15/05/2020
Repairment date: 16/05/2020
Repairment time: 05:12
c7
c1
c2

Figure 5. Maintenance plan: a) Test_case#1 and b) Test_case#2.

5 CONCLUSION

At the present deliverable the development of the MCDA tool and the results of two different test cases have been presented. From the analysis of the results, we can conclude that the results are mainly affected of the criteria's weights. Additionally, even if in Test_case#2 the weight of the working hours of the personnel has been set to a higher value, the working hours of the optimal solutions are extremely high. Considering these, the weights of the model should be carefully assigned and the knowledge of the expert is required in order to reject or accept the approaches.

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