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# Development of fuzzy RUASP model - Grasp metaheuristics with time window: Case study of Mount Semeru eruption in East Java

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**Abstract.** Due to its geographical location, Indonesia is very vulnerable to the volcano eruption. Volcanic eruptions always bring impact to the surrounding community. To mitigate the negative effects, especially the impact on the safety of the population, disaster management is required. One of the concerns of disaster management is a proper allocation and scheduling of rescue teams to minimize evacuation time with expectations of saving as many lives as possible. For that purpose, the RUASP (Rescue Unit Assignment and Scheduling Problem) optimization model is developed to minimize a completion time of evacuation. The model considers the severity of damages and capability of the rescue team as well as safety time for the rescue team. There is a period for rescue teams to be able to perform their duties safely and fuzzy time on the fields. Physical limitations and device limitations are the inhibiting factors for evacuation activities during low light conditions. We also developed a GRASP Metaheuristics algorithm for solving the proposed RUASP model. To test the model we use a certain historical data. The completion time of the proposed model is 21.92% faster than the computation time of the previous model, 12.56 seconds.

## 1. Introduction

Indonesia is an archipelago that is vulnerable to natural disasters, including volcanic eruptions. This is due to Indonesia's geographical location, which is located on the Pacific Ring of Fire and at the meeting point of 4 tectonic plates, namely the Asian continental plate, the Australian continental plate, the Indian Ocean plate, and the Pacific Ocean plate. In the South and East Indonesia, there are also volcanic arcs stretching from Sumatra, Java, Nusa Tenggara, to Sulawesi, namely old volcanic mountains and lowlands which are partly dominated by swamps [1]. Volcanic eruptions are very dangerous because they cause hot clouds, bursts of material (incandescent), heavy ash rain, lava, poison gas, lava floods, and even tsunamis. Apart from causing many casualties, the eruption also caused huge economic losses due to the amount of damaged infrastructure and the high recovery costs.

Altay & Green [2] stated there are four phases of disaster management, namely mitigation, preparedness, response and recovery phase. In this research, we focused on the response phase (or usually called an emergency response). Certain efforts are carried out in dealing with the adverse impacts of such disasters, such as rescue and evacuation of victims, property, basic needs, protection, refugee management, rescue, and recovery of infrastructure and facilities [3]. In the response phase, it needs more attention and quick, precise, and responsive handling, especially to evacuate the victims. The



evacuation of victims is undoubtedly inevitable during the emergency response. The proper allocation and scheduling of rescue teams are needed to minimize evacuation time with the expectation to save as many lives as possible.

Santoso *et al.* [4] developed optimization model of rescue team assignment and scheduling problem that is used as the previous model in this research. This RUASP model that aims to minimize completion time can be classified to be quite a complex model. The RUASP model considered many important factors that have been considered, such as factors of severity and capability of the rescue team. However, there is still something crucial that has not been considered in this mode, which is the time duration for rescue teams to perform their duties safely. Physical limitations and device limitations are the inhibiting factors for evacuation activities during low light conditions. To deal with the condition, the time window constraints need to be added in the model because if this model does not include the use of time window, it will be risky to the safety of the rescue team itself when they are on-duty later. Therefore, the use of time window needs to be considered in the proposed model to anticipate this and refine the existing model.

In the proposed model, we deal with how to determine the allocation and scheduling of the appropriate rescue team to avoid casualties during a certain period, as well as not endanger the safety of the on-duty rescue team. The outputs of this proposed model are the allocation and scheduling of the proper rescue team with the minimum completion time under time window. Because the proposed model is categorized as mixed integer linear programming, consequently the proposed RUASP model is classified as NP-Hard model [5]. Therefore, we have to solve the proposed RUASP model using the GRASP (Greedy Randomized Adaptive Search Procedure) Metaheuristics method.

## 2. Research Method

To achieve the objectives of this research, systematic and structured steps are required in order not to deviate from the path. The first step is to identify the problem. The problem is the previous RUASP model did not consider the time window. The second step is to do the necessary literature study. The third step is to define the formulation and the purpose of the problem to be achieved. The fourth step is to set up a scenario that consists of some data obtained in the field (such as the location of the incident) and some assumption data (such as operational time). The fifth step is to arrange MATLAB programming for the previous method of the GRASP Metaheuristics. After that, the validation test and analysis of the results are conducted. The model can be then developed through analysis of the results, followed by the preparation of MATLAB programming for the proposed method of GRASP Metaheuristics. Validation test and result analysis are also done on this proposed method. The next is to do a sensitivity analysis, and the last step is to make conclusions and suggestions.

The GRASP (Greedy Randomized Adaptive Search Procedure) Metaheuristics is a metaheuristic algorithm that provides a variety of solutions from existing construction heuristics. The use of GRASP Metaheuristics aims to address the shortcomings of pre-built heuristics, which only provide the same solution repeatedly [6]. With the use of GRASP Metaheuristics, it will get the most optimal solution. In the GRASP Metaheuristics itself, there are 2 phases to do. The first phase is the construction phase, which in this phase the heuristic used will produce a feasible solution. Then, the second phase is the local search phase, which in this phase will be searching for the most optimal solution of the heuristic that has been developed.

## 3. Model Development

The proposed model is developed based on Santoso *et al.* [4] model and to be added by a time window constraints. This limitation is necessary considering that evacuation activities should also take into account the safety period for rescue teams while on duty. The safety of rescue teams can be influenced by natural factors, especially the potential for an eruption of volcanoes, physical limitations, and limitations of the tool when conditions in the field are poor (i.e., dark). Based on the information from BPBD Lumajang, good evacuation activity usually starts at 07.00 when the sun is shining and ends at the latest at 17.00 before sunset. If evacuation activities continue in the dark, then, as explained earlier,

this can be difficult and even endanger the safety of the rescue team on duty. This period will be the time window of this study. This time window is categorized as hard time window with the same logic as time window in VRP as what Cordeau et al. [7] said. If the VRP vehicles are not allowed to perform services outside the period, then, in this case, the rescue team is not allowed to perform its duties in the period. There is no penalty because the team can only serve the location of the incident within the available time frame. Good evacuation activities should be able to save lives without causing casualties of another, especially from the rescue team itself. Therefore, the addition of time window constraints in the model is the best solution to solve this problem.

3.1. Mathematics Notation.

The mathematics notations are used in this proposed RUASP model consists of parameters and decision variables, as follows:

Parameter

$n$	Number of incidents, with the set $I = (1, \dots, n)$
$m$	Number of rescue teams, with set $K = (1, \dots, m)$
$w_j \in R^{\geq 0}$	The factor of severity of incident $j$
$p_j^k \in R^{\geq 0}$	Operational time of rescue team $k$ to process incident $j$ ; $\infty$ if rescue team $k$ is unable to process incident $j$ .
$s_{ij}^k \in R^{\geq 0}$	The travel time of rescue team $k$ to move from incident $i$ to incident $j$ ; if $i = 0$ then rescue team $k$ is at the starting location (post) before going to the location of the incident $j$
$cap_{ki} \in \{0,1\}$	1 if rescue team $k$ is able to overcome incident $i$ ; 0 otherwise.
$t_{ik}$	The arrival time of rescue team $k$ at incident $i$
$[t_{wa}, t_{wb}]$	Available time window

Decision Variables

$X_{ij}^k \in \{0,1\}$	1 if incident $i$ is processed by the rescue team $k$ immediately before processing the incident $j$ ; 0 otherwise.
$Y_{ij}^k \in \{0,1\}$	1 if incident $i$ is processed by rescue team $k$ any time before processing incident $j$ ; 0 otherwise.

3.2. Mathematical Formulation.

According to Santoso et al. [4], the objective of the proposed RUASP model is to minimize the sum of weighted completion times overall incidents. The weighted completion time consists of processing time for rescuing the victims and traveling time. However, the processing time depends on the ratio of required capability at the area of the incident to the capacity of the available rescue team. Also, the proposed RUASP model use the fuzzy concepts for the weight of completion time and for traveling time.

$$\min \quad Z = \sum_{j=1}^n (T \sum_{i=0}^n \sum_{k=1}^m [C_i^k p_i^k Y_{ij}^k + (C_j^k p_j^k + U) X_{ij}^k + Y_{ij}^k (\sum_{l=0}^n X_{li}^k V)]) \tag{1}$$

where

$$T = 0.3lw_j + 0.4mw_j + 0.3uw_j \tag{1a}$$

$$U = 0.3ls_{ij}^k + 0.5ms_{ij}^k + 0.2us_{ij}^k \tag{1b}$$

$$V = 0.3ls_{ii}^k + 0.5ms_{ii}^k + 0.2us_{ii}^k \tag{1c}$$

Constraints

$$\sum_{i=0}^n \sum_{k=1}^m X_{ij}^k = 1, \quad j = 1, \dots, n \tag{2}$$

$$\sum_{j=1}^{n+1} \sum_{k=1}^m X_{ij}^k = 1, \quad i = 1, \dots, n \tag{3}$$

$$\sum_{j=1}^{n+1} X_{0j}^k = 1, \quad k = 1, \dots, m \tag{4}$$

$$\sum_{i=0}^n X_{i,n+1}^k = 1, \quad k = 1, \dots, m \tag{5}$$

$$Y_{il}^k + Y_{ij}^k - 1 \leq Y_{ij}^k, \quad i=0, \dots, n; j = 1, \dots, n+1; k = 1, \dots, m; l = 1, \dots, n \tag{6}$$

$$\sum_{i=0}^n X_{il}^k = \sum_{j=1}^{n+1} X_{ij}^k, \quad l = 1, \dots, n; k = 1, \dots, m \tag{7}$$

$$X_{ij}^k \leq Y_{ij}^k, \quad i = 0, \dots, n; j = 1, \dots, n + 1; k = 1, \dots, m \tag{8}$$

$$Y_{ii}^k = 0, \quad i = 0, \dots, n + 1; k = 1, \dots, m \tag{9}$$

$$Y_{ij}^k \leq cap_{ki}, \quad i = 1, \dots, n; j = 1, \dots, n + 1; k = 1, \dots, m \tag{10}$$

$$\sum_{l=1}^{n+1} X_{il}^k \geq Y_{ij}^k, \quad i = 0, \dots, n; j = 1, \dots, n + 1; k = 1, \dots, m \tag{11}$$

$$\sum_{l=0}^n X_{lj}^k \geq Y_{ij}^k, \quad i = 0, \dots, n; j = 1, \dots, n + 1; k = 1, \dots, m \tag{12}$$

$$X_{ij}^k, Y_{ij}^k \in \{0,1\}, \quad i = 0, \dots, n; j = 1, \dots, n + 1; k = 1, \dots, m \tag{13}$$

$$t_{jk} \geq t_{ik} + X_{ij}^k p_i^k + X_{ij}^k (0.3ls_{ij}^k + 0.5ms_{ij}^k + 0.2us_{ij}^k) \quad i=0, \dots, n; j = 1, \dots, n+1; k = 1, \dots, m \tag{14}$$

$$t_{wa} \leq t_{n+1,k} \leq t_{wb} \quad k = 1, \dots, m \tag{15}$$

Constraint (2) is used to ensure that the incident  $j$  must have originated from one of the incidents  $i$  handled by one of the rescue teams  $k$ . Constraints (3) is used to ensure that the episode  $i$  must go to one of the locations of the incident  $j$  handled by one of the rescue teams  $k$ . Constraints (4) and (5) are used to ensure that any rescue team will start the search from the post and will return to the post as well after completing the task. Constraint (6) denotes the sequence that  $i$  must precede  $j$ . Constraint (7) is used to ensure that the rescue team  $k$  will go to another location point or return. Constraint (8) is used to ensure that if a point of location is directly handled by the rescue team  $k$ , then the point should be present. Constraint (9) is used to ensure that the rescue team does not stick in a location and can move to another location. Constraint (10) is used to ensure that if the rescue team  $k$  has sufficient capability to process incident  $i$ , then the rescue team  $k$  can process it. Constraints (11) and (12) are used to ensure that  $Y_{ijk}$  will be 0 if the rescue team  $k$  does not process the incident  $i$  before the incident  $j$ . Constraint (13) is used to ensure that the value and is binary. Constraint (14) is used to ensure that the rescue team's time comes at a further location at least from the time the rescue team handles the previous location. The time the rescue team handled the previous location consisted of the rescue team's arrival time at the previous location plus the rescue team's operational time at the previous location and the rescue team's travel time from the last position to the next. Constraint (15) is used to ensure that rescue teams return to posts that are not beyond the designated period. Thus, the safety of the rescue team can still be guaranteed

3.3. GRASP Metaheuristics.

Changes to the mathematical model resulted in an adjustment to the GRASP Metaheuristics steps. The following is the overall pseudocode of proposed method - GRASP Metaheuristics

```

PROPOSED METHOD - GRASP METAHEURISTICS
Input parameter & initialization variable
while iter < maxiter
Update  $S \leftarrow \theta$ 
Count completion time (C)
while i > 0
Count  $C_{\min} \leftarrow \min \{c|c \in C\}$  and  $C_{\max} \leftarrow \max \{c|c \in C\}$ 
Check RCL  $\leftarrow \{c \in C | c \leq C_{\min} + \alpha(C_{\max} - C_{\min})\}$ 
Select random value  $c \in RCL$  with its index location and team
Do construction heuristics
Update  $C \leftarrow C \setminus \{i^*\}$ 
end while
Save the chosen incident to the schedule
Do improvement heuristics from that schedule
Update schedule & count completion time
if  $twa \leq completiontime \leq twb$ 
Save completion time with its schedule
end if
end while
Select the smallest completion time with its schedule
    
```

**Figure 1.** Pseudocode of Proposed Method

**4. Results and discussion**

*4.1. Data.*

The data to be applied to the model comes from the data obtained in the field and the assumptions data. The data obtained in the field comes from “Renkon Mount Semeru Year 2015”. It is the data related to the number of location of the incident that reached 17 locations and the location of the post that is located in Lumajang city. Meanwhile, assumption data is data that is not found in the field but deliberately created by using a particular distribution approach and fuzzy logic to describe the actual conditions in the field. These data include location, severity, number of teams available, team’s travel time, the team’s operational time, team’s capability, and required capabilities in each incident location, etc.

*4.2. Proposed model test.*

Based on the scenario that has been made plus the time window from 07.00-17.00, then the proposed model is made. The following is the result of the proposed model in the form of scheduling.

**Table 1.** Team Schedule

Team	Start	Destination	A minutes	Arrive	B minutes	Depart	Finish	C minutes
1	07.00	1. Pronojiwo	74	08.14	86	09.40	15.15	495
		2. Sumberrejo	36	10.16	110	12.06		
		3. Gesang	28	12.34	42	13.16		
		4. Nguter	8	13.24	69	14.33		
		5. Post	42	15.15	-			
2	07.00	1. Jogosari	85	08.25	112	10.17	12.39	339
		2. Sememu	38	10.55	73	12.08		
		3. Post	31	12.39	-			
3	07.00	1. Sumbermujur	67	08.07	75	09.22	14.15	435
		2. Sumber Urip	38	10.00	67	11.07		
		3. Kloposawit	46	11.53	90	13.23		
		4. Post	52	14.15	-			

Team	Start	Destination	A minutes	Arrive	B minutes	Depart	Finish	C minutes
4	07.00	1. Kertosari	50	07.50	116	09.46	12.43	343
		2. Penanggal	22	10.08	100	11.48		
		3. Post	55	12.43	-			
5	07.00	1. Jatisari	27	07.27	62	08.29	08.56	116
		2. Post	27	08.56	-			
6	07.00	1. Supit Urang	85	08.25	68	09.33	14.18	438
		2. Oro-Oro Ombo	20	09.53	73	11.06		
		3. Pasrujambe	59	12.05	64	13.09		
		4. Post	69	14.18	-			
7	07.00	1. Sumberwuluh	67	08.07	99	09.46	12.32	332
		2. Gondoruso	45	10.31	59	11.30		
		3. Post	62	12.32	-			

A=Travel Time, B=Operational Time, C=Total Time

From Table 1, it can be seen that the completion time model of this proposed is 495 minutes (8 hours 15 minutes). Meanwhile, the computation time to get the result is 12.56 seconds. In this proposed model, iteration was done 300 times to get the result. From the validation test, the result of this proposed model is also valid.

The addition of this time window constraint shows a significant effect because these limits can make a more optimal result for a "safe period" to ensure the safety of rescue team on duty. Table 2 shows the completion time, which initially took 528 minutes, now takes 495 minutes. The proposed model produces completion time 6.25% faster than the previous model.

**Table 2.** Comparison of previous Model to Proposed Model Result

	Completion Time	Difference	% Difference
Previous model	528 minutes		
Proposed model	495 minutes	33 minutes	$\frac{33}{528} \times 100\% = 6.25\%$

As described above, it can be concluded that the previous model was also able to produce a solution that is almost optimal as the proposed model (the difference is 6.25%), but with some iterations as many as the proposed model does. Without time window constraints, it will be difficult to know how much iteration is needed to produce a more optimal solution. There is a difference of 16.72% out of the previous model trials generated as many as 100 iterations and 300 iterations. Therefore, it turns out that the role of the time window is very important to be applied. First, it is because time window constraints can ensure the safety of rescue teams while on duty. Second, it is because time window constraints can force the model to run more iteration to make a more optimal solution.

Also, regarding load balancing, the results of the proposed model is not much different compared to the previous model. The workload of each team is still imbalanced, and it is because the team with low capability cannot be assigned more to make a balance. The only way to ease of creating load balancing is to increase the capacity of all teams to be equally higher.

#### 4.3. Sensitivity analysis.

A sensitivity analysis is conducted to investigate the effect or effect changes certain parameters on the value of the optimal solution (objective function) generated [8]. A goal function can be said to be sensitive to a parameter if the percentage change in the value of the objective function is greater than the percentage change of the parameter. This sensitivity analysis becomes very important considering that sometimes there are many parameters as the result of estimation. Any changes to certain parameters will affect the quantity of optimality and feasibility of the optimized solution is generated. Sensitivity analysis is done by changing the value of a parameter. The first parameter to be tested is the team's

operational time. The operational time of the team can change at any time due to various things so that the operation time can be faster or slower. It is faster if the team can find the victim less than the expected time. Slower if the team encounters difficulties on a particular terrain that turns out to be beyond expectations. The second parameter chosen is the capability of a team. This parameter is selected to see how much team capability affects completion time, such as by, for example, creating the value of team capability at the same time and a certain high value.

**Table 3.** Analysis of Results of Changes in Objective Functions on Change of Team Operational Time

% Parameter Change	% Objective Function Change	Completion Time (minutes)
20%	19.79%	593
10%	2.63%	508
0%	0%	495
-10%	-8.89%	451
-20%	-10.30%	444

From the results obtained, it was found that the percentage change of objective function is not more than changes in team operational time. Therefore, it can be concluded that the objective function is not sensitive to changes in team operational time parameters. Also, it can be seen that the relationship between the completion times of the team operational time is directly proportional. The higher the change of team operational time, the higher the value of completion time is and vice versa.

**Table 4.** Consumption Time for Going Back to Post of Each Team at Any Change of Operational Time

Team	Consumption Time for Going Back to Post				
	Decrease 20%	Decrease 10%	Normal	Increase 10%	Increase 20%
1	09.17	10.20	15.15	15.20	16.02
2	12.57	09.08	12.39	12.57	09.38
3	13.51	13.52	14.15	15.19	16.53
4	10.19	14.31	12.43	10.48	12.23
5	08.57	08.49	08.56	09.04	09.10
6	14.24	13.41	14.18	14.15	15.13
7	13.50	14.16	12.32	15.28	15.59

Through Table 4, it can be seen once again that there is an imbalance of workload of each team. Teams with low capability values tend to return to the post early because they handle only a few incident sites. Meanwhile, teams with high capability value tend to return to the post longer because they have to handle many incident sites.

**Table 5.** Analysis of Results of Changes in Objective Functions on Change of Team Capability

% Parameter Change	% Objective Function Change	Completion Time (minutes)
10%	-16.97%	411
5%	-15.35%	419
0%	0%	495
-5%	5.66%	523
-10%	31.72%	652



Based on Table 5, it can be seen that the percentage change in objective function is greater than the percentage change in the parameters of team capability. The negative number that occurs only indicates that the objective function is decreasing. Therefore, it can be concluded that the objective function is sensitive to changes in team capability parameters. Also, it can be seen that the relationship between the completion times of change in team capability is inversely proportional. The higher the team capability changes, the lower the resulting completion time do and vice versa.

**Table 6.** Consumption Time for Going Back to Post of Each Team at Any Change of Team Capability

Team	Consumption time for going back to Post				
	Decrease 10%	Decrease 5%	Normal	Increase 5%	Increase 10%
1	14.39	14.22	15.15	13.37	12.40
2	09.40	10.56	12.39	13.54	10.47
3	14.48	15.40	14.15	13.23	13.14
4	11.46	12.26	12.43	11.34	12.21
5	09.15	09.04	08.56	08.49	12.43
6	17.52	14.30	14.18	13.59	13.51
7	15.43	15.43	12.32	12.23	12.04

Table 6 once again proves that team capability greatly affects the workload of the team which in this case appears from the duration each team returns to the post. The lower the capability of a team signifies that the team is not able to handle the location of more incidents due to its limited ability. As a result, the team can only handle a few incidents, go home early to the post and vice versa. Increasing the capability of a team, the team can handle the location of the incident even more because it can overcome the incident. Thus, the workload of each team can be more balanced to each other and completion time becomes faster.

## 5. Conclusion

There are two conclusions in this research. First, the RUASP model was developed by adding 2 time window constraints and adjustments to its GRASP Metaheuristics steps. The results of 300 iterations are 8 hours 15 minutes for the completion time and 12.56 seconds for the computation time. Completion time of the proposed model is 6.25% faster than the previous model. The time window constraints force the model to run more iteration so that the solution is the most optimal solution. The previous model which is run for 100 iterations only, need to be run with 300 iterations to have a fair comparison. The results obtained have a difference of 6.25% longer than the results of the proposed model. The previous model was also able to produce the optimal solution similar to the proposed model, but with some iterations as many as the proposed model does. Without time-window constraints, it will be difficult to know how much repetition is needed to produce a more optimal solution. There is a difference of 16.72% out of the previous model trials conducted as many as 100 iterations and 300 iterations. Therefore, the role of time window constraints can be said to be very crucial as it helps to obtain the most optimal solution. Also, in the proposed model results, there is still an imbalance of team workload even though the model has already taken into account load balancing. This is because there are some teams with low capabilities so they can handle only a few locations. Second, the sensitivity analysis shows that the objective function is not sensitive to changes in team operational time, but to changes in team capability.

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