5: Test case

- In every instance, the number of depots is fixed at one according to the problem statement. Relief supplies are assumed to be delivered by rotary-wing unmanned aerial vehicles.
- The size of each instance is varied by changing two elements:
  (i) The number of candidates charging-station nodes, and
  (ii) The number of demand nodes.
- Travel time for the drone to move from location i to location j is modeled as a fuzzy random variable

$$\tilde{t}_{ij}^{s} = \left(t_{ij}^{s}, t_{ij}^{\alpha}, t_{ij}^{\beta}\right), \quad t_{ij}^{s} \sim \left(\mu_{\tilde{t}_{ij}^{s}}, \sigma_{\tilde{t}_{ij}^{s}}^{2}\right)$$

  Where

$$t_{ij}^{\alpha} \in \left[\mu_{\tilde{t}_{ij}^{s}} - 5, \mu_{\tilde{t}_{ij}^{s}}\right], \quad t_{ij}^{\beta} \in \left[\mu_{\tilde{t}_{ij}^{s}}, \mu_{\tilde{t}_{ij}^{s}} + 5\right]$$

- Travel time reliability on (i, j) is captured by another fuzzy number

$$\tilde{r}_{ij} = \left(r_{ij}, r_{ij}^{\alpha}, r_{ij}^{\beta}\right)$$

  where

$$r_{ij}^{\alpha} \in \left[r_{ij} - 0.2, r_{ij}\right], \quad r_{ij}^{\beta} \in \left[r_{ij}, r_{ij} + 0.2\right]$$

- The drones can be equipped with various configurations to carry 4, 8, or 10 packages, representing their maximum payload capacities. These options represent distinct choices; in each case, one is selected based on operational constraints or problem requirements.
- Similarly, the maximum battery energy capacity is modeled as a multi-choice parameter with three discrete options: 60, 100, and 200 kilojoules. Each value represents a possible configuration of the drone's battery system and is selected based on the problem requirements. The problem parameters are summarized in Table 4.

Table 4: Problem Parameters

Parameter	Value
$\tilde{t}_{ij}^{s}$	$\left(t_{ij}^{s} \sim \left(\mu_{\tilde{t}_{ij}^{s}}, \sigma_{\tilde{t}_{ij}^{s}}^{2}\right), t_{ij}^{\alpha}, t_{ij}^{\beta}\right)$
t_{ij}^{α}	$\left[\mu_{\tilde{t}_{ij}^{s}} - 5, \mu_{\tilde{t}_{ij}^{s}}\right]$
t_{ij}^{β}	$\left[\mu_{\tilde{t}_{ij}^{s}}, \mu_{\tilde{t}_{ij}^{s}} + 5\right]$

$\tilde{r}_{ij}$	$\left(r_{ij}, r_{ij}^{\alpha}, r_{ij}^{\beta}\right)$
r_{ij}^{α}	$\left[r_{ij} - 0.2, r_{ij}\right]$
r_{ij}^{β}	$\left[r_{ij}, r_{ij} + 0.2\right]$
e_{TL}^{0}	0.5
e_{TL}^{+}	1.5
e_{F}^{0}	4
e_{F}^{+}	5

To compute the numerical values of the environmental condition parameter (λ^{α} and λ^{β}), the following environmental inputs are considered using a FIS:

Wind = 25 (km/h)

Temperature = 28 (°C)

Altitude = 1500 (m)

In real-world applications, FISs are typically designed based on expert knowledge, where specialists define the rules and fuzzy values according to their domain experience. In this test case, the authors defined these components using their domain knowledge and experience. Therefore, the fuzzy values corresponding to the three fuzzy sets F_W, F_T and F_A are defined as illustrated in Figure 4.

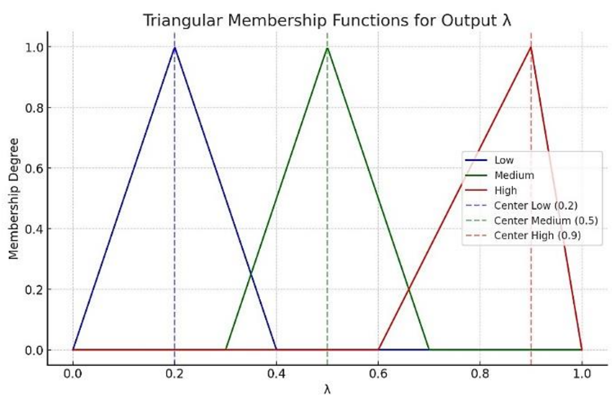

Figure 4: Triangular membership functions for λ with centers at 0.2 (Low), 0.5 (Medium), and 0.9 (High).

Based on the membership functions defined in Figure 3, the membership degrees for the above input values are obtained as follows:

Wind = 25 (km/h) $\Rightarrow$ $\mu(Low) = 0,$ $\mu(Medium) = 0.75,$ $\mu(High) = 0$

Temp = 28 (°C) $\Rightarrow$ $\mu(Cold) = 0,$ $\mu(Moderate) = 0.2,$ $\mu(Hot) = 0.2$

Altitude = 1500 (m) $\Rightarrow$ $\mu(Low) = 0,$ $\mu(Medium) = 0.58,$ $\mu(High) = 0$

Finally, by defining the fuzzy rules R_k, and using the membership functions defined in Figure 3, as well as equations (9) and (11), we obtain:

$$\lambda^{\alpha} = 0.70$$

$$\lambda^{\beta} = 0.875$$

Based on the generated parameters, the proposed model was implemented using GAMS version 24.1.2 on a personal computer equipped with a 2.0 GHz processor and 4 GB of RAM running the Windows operating system. The results obtained for several representative values of γ_0 (i.e., 0.6, 0.7, 0.8, and 0.9) are presented in Table 5 and Figure 5.

Table5: The results obtained for different values of γ_0 and the Crisp Objective function Value

Instances	Nodes	γ_0	Selected P_{max} and E_{max}	Obj	Crisp Obj
1	$N = 7 = \begin{cases} O = 1 \\ R = 1 \\ L = 5 \end{cases}$	$\gamma_0 = 0.6$ $\gamma_0 = 0.7$ $\gamma_0 = 0.8$ $\gamma_0 = 0.9$	$u = 1$ & $v = 2$ $u = 1$ & $v = 2$ $u = 1$ & $v = 2$ $u = 1$ & $v = 2$	9.316 9.350 9.390 9.443	9.000
2	$N = 8 = \begin{cases} O = 1 \\ R = 2 \\ L = 5 \end{cases}$	$\gamma_0 = 0.6$ $\gamma_0 = 0.7$ $\gamma_0 = 0.8$ $\gamma_0 = 0.9$	$u = 1$ & $v = 2$ $u = 1$ & $v = 2$ $u = 1$ & $v = 2$ $u = 1$ & $v = 2$	6.067 6.090 6.118 6.155	5.556
3	$N = 9 = \begin{cases} O = 1 \\ R = 2 \\ L = 6 \end{cases}$	$\gamma_0 = 0.6$ $\gamma_0 = 0.7$ $\gamma_0 = 0.8$ $\gamma_0 = 0.9$	$u = 1$ & $v = 2$ $u = 1$ & $v = 2$ $u = 2$ & $v = 2$ $u = 2$ & $v = 2$	5.711 5.733 5.759 5.795	5.189
4	$N = 10 = \begin{cases} O = 1 \\ R = 2 \\ L = 7 \end{cases}$	$\gamma_0 = 0.6$ $\gamma_0 = 0.7$ $\gamma_0 = 0.8$ $\gamma_0 = 0.9$	$u = 1$ & $v = 2$ $u = 1$ & $v = 2$ $u = 2$ & $v = 2$ $u = 2$ & $v = 2$	6.177 6.199 6.224 6.259	5.246
5	$N = 11 = \begin{cases} O = 1 \\ R = 2 \\ L = 8 \end{cases}$	$\gamma_0 = 0.6$ $\gamma_0 = 0.7$ $\gamma_0 = 0.8$ $\gamma_0 = 0.9$	$u = 2$ & $v = 2$ $u = 2$ & $v = 2$ $u = 2$ & $v = 2$ $u = 2$ & $v = 2$	5.136 5.154 5.176 5.205	4.655
6	$N = 12 = \begin{cases} O = 1 \\ R = 2 \\ L = 9 \end{cases}$	$\gamma_0 = 0.6$ $\gamma_0 = 0.7$ $\gamma_0 = 0.8$ $\gamma_0 = 0.9$	$u = 2$ & $v = 2$ $u = 2$ & $v = 2$ $u = 1$ & $v = 2$ $u = 1$ & $v = 2$	6.145 6.164 6.187 6.217	5.616
7	$N = 13 = \begin{cases} O = 1 \\ R = 2 \\ L = 10 \end{cases}$	$\gamma_0 = 0.6$ $\gamma_0 = 0.7$ $\gamma_0 = 0.8$ $\gamma_0 = 0.9$	$u = 2$ & $v = 2$ $u = 2$ & $v = 2$ $u = 2$ & $v = 2$ $u = 1$ & $v = 2$	5.955 5.973 5.995 6.024	5.422

8	$N = 14 = \begin{cases} O = 1 \\ R = 2 \\ L = 11 \end{cases}$	$\gamma_0 = 0.6$	$u = 1$ & $v = 2$	6.529	6.000
		$\gamma_0 = 0.7$	$u = 1$ & $v = 2$	6.546	
		$\gamma_0 = 0.8$	$u = 1$ & $v = 2$	6.567	
		$\gamma_0 = 0.9$	$u = 2$ & $v = 2$	6.595	
9	$N = 15 = \begin{cases} O = 1 \\ R = 3 \\ L = 11 \end{cases}$	$\gamma_0 = 0.6$	$u = 1$ & $v = 2$	5.860	5.324
		$\gamma_0 = 0.7$	$u = 2$ & $v = 2$	5.877	
		$\gamma_0 = 0.8$	$u = 2$ & $v = 2$	5.898	
		$\gamma_0 = 0.9$	$u = 2$ & $v = 2$	5.926	