System Architecture for eVTOL-based Emergency Medical Services

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System Descriptions (Research Question)

The architecture of the operational system of e-VTOLs for emergency medical service in the urban area is designed. What kind of architecture are optimal?

- The system is **responsive**, **energy efficient**, and **economical**.

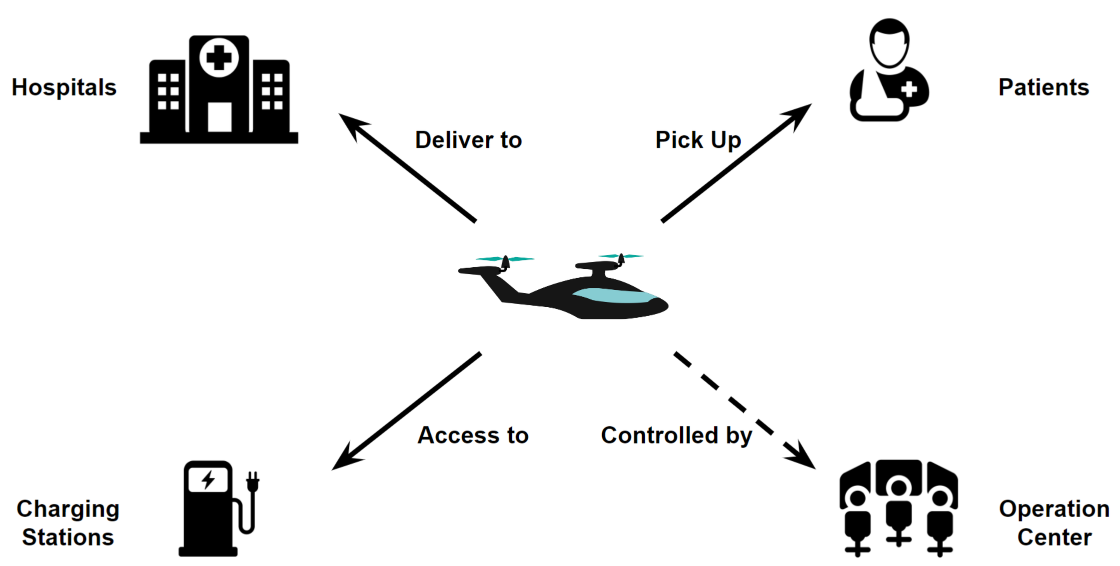


Figure 1. System Overview

Architectural Decisions

Nine important decisions and their option space are shown in Figure 2. Constraints only exist between decisions A (level of autonomy of e-VTOLs), B (Ownership of e-VTOLs), and I (e-VTOL suppliers).

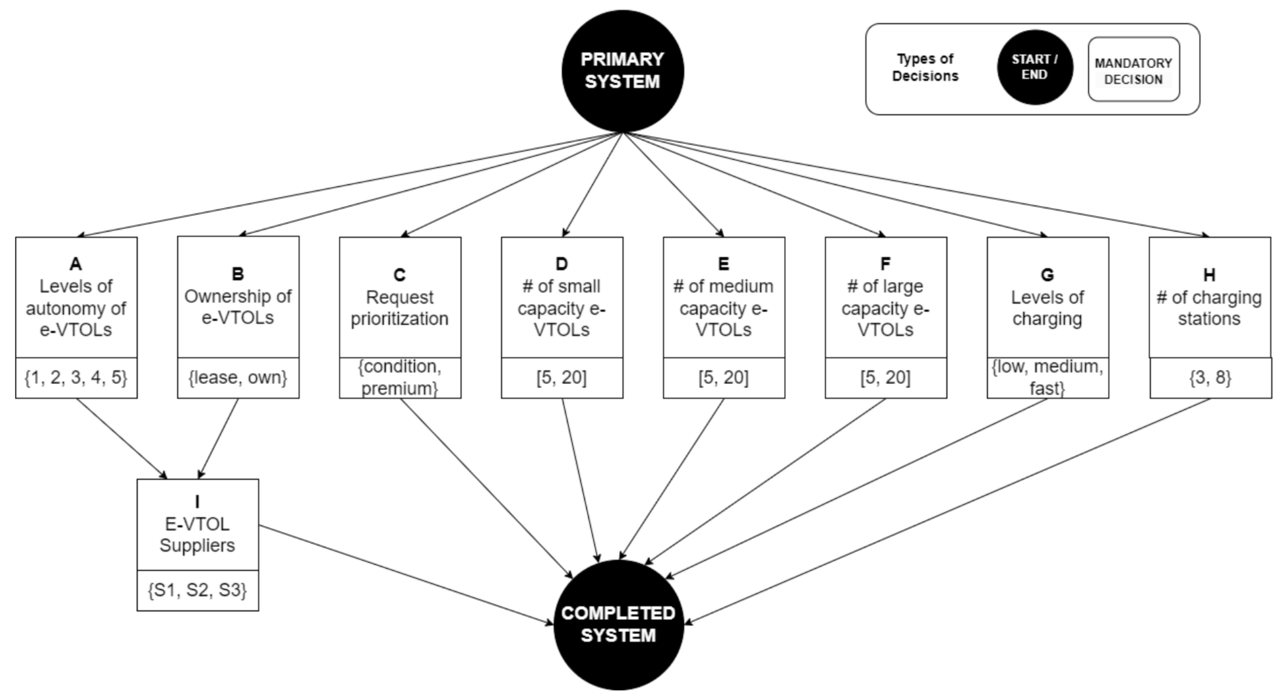


Figure 2. Important Architectural Decisions

Data: Metrics and Evaluation

One cost metric + one reliability metric +two performance metrics

- **NPV:** The net present value of the total expense in 10 years
- **Service Rate:** The ratio of the # of served patients to the total # of patients
- **Response Time:** The average response time to a request

The NPV is computed as follows

$$NPV = \frac{\sum_{t=0}^{10} C_t}{(1+\gamma)^t}$$

Service rate and response time are computed based on the following quantities. The charging time T is normally distributed: $T \sim N(\mu_T, \sigma_T^2)$. The density of charging is uniformly distributed: $D \sim U(a, b)$. The request arrival follows a Poisson distribution: $N \sim \text{Poisson}(\lambda)$. The delay time is exponentially distributed: $D \sim \text{Exp}(\lambda_D)$. These quantities are simulated for a day in a small region of the city.

Methods: Tradespace Exploration

- **35,000 feasible** architectures were enumerated.
- Only three objectives (NPV, service rate, and response time) are adopted to explore the **trade-off between cost and performance**.

Fuzzy Pareto Data Mining and Dominant Decisions

We generated rank1 and rank2 Pareto front to mine the importance of the decision variables. The importance is calculated based on lift, support, and confidence calculations.

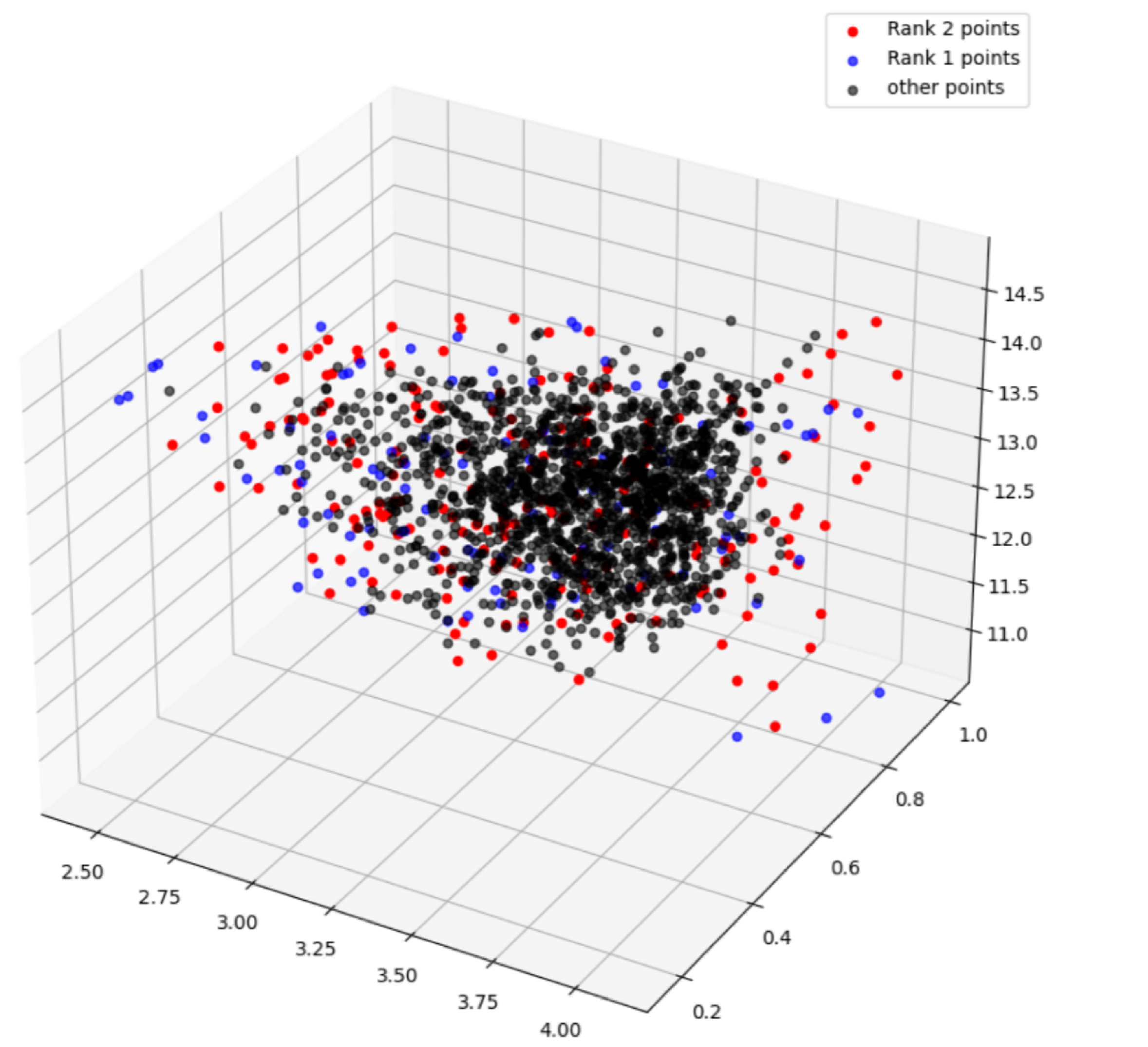


Figure 3. Visualization of The Tradespace

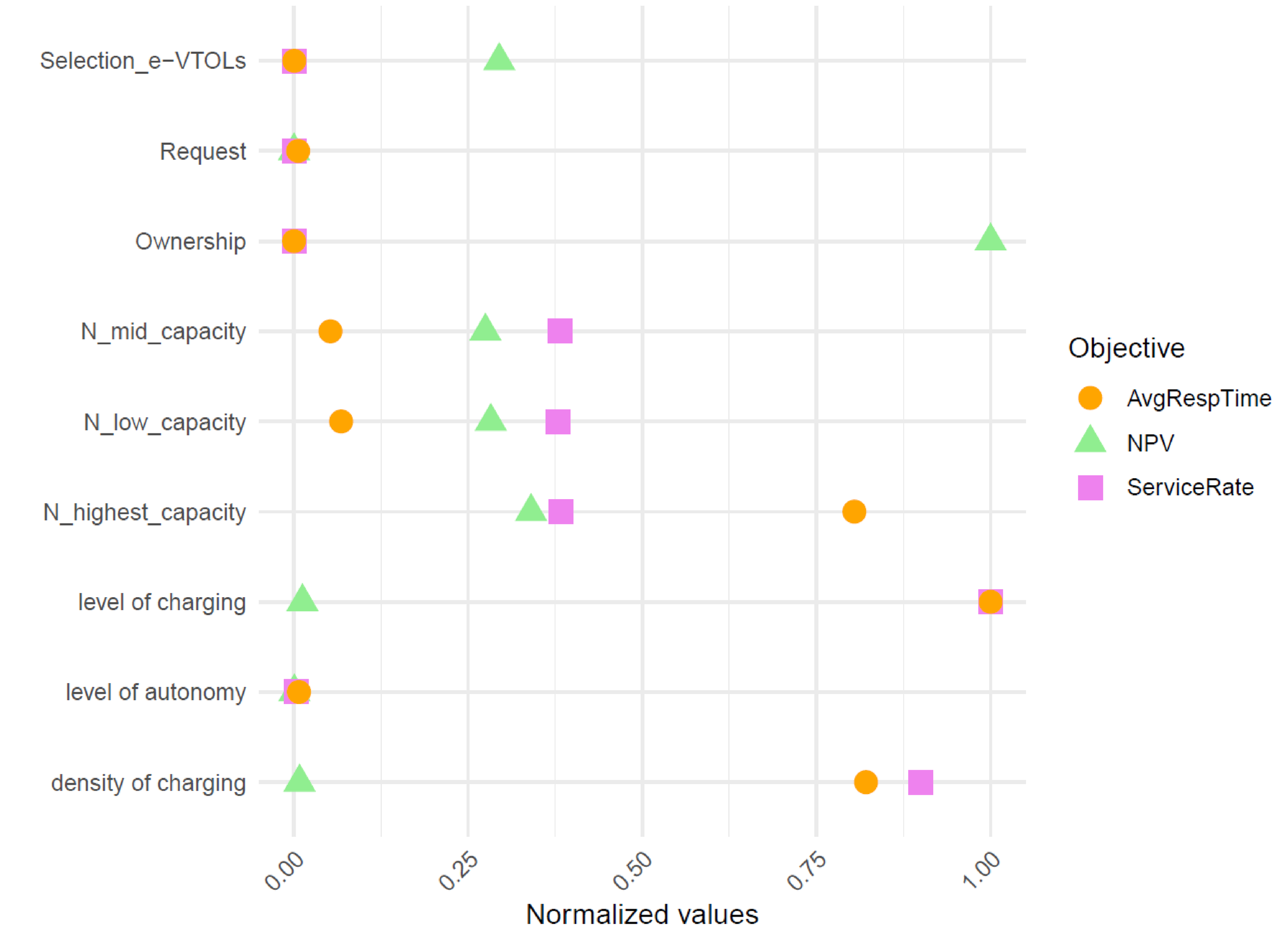


Figure 4. Dominant Decisions Variable for Architectures

Implication: Capacity and Charging related decisions are more dominant across objectives. Ownership is not that important from response and service rate and only for cost.

Multi-Objective Optimization

We optimize the architecture with a multi-objective genetic algorithm. We employ a two-stage selection function which first randomly selects a metric and secondly, an individual based on roulette wheel selection on the selected metric. We use the pyeasyga python [1] library with custom functions.

#of low capacity e-vtol	#of medium capacity e-vtol	#of high capacity e-vtol	level of charging	density of chargers	ownership	prioritization	e-vtol supplier	autonomy level

Figure 5. Design of Chromosome

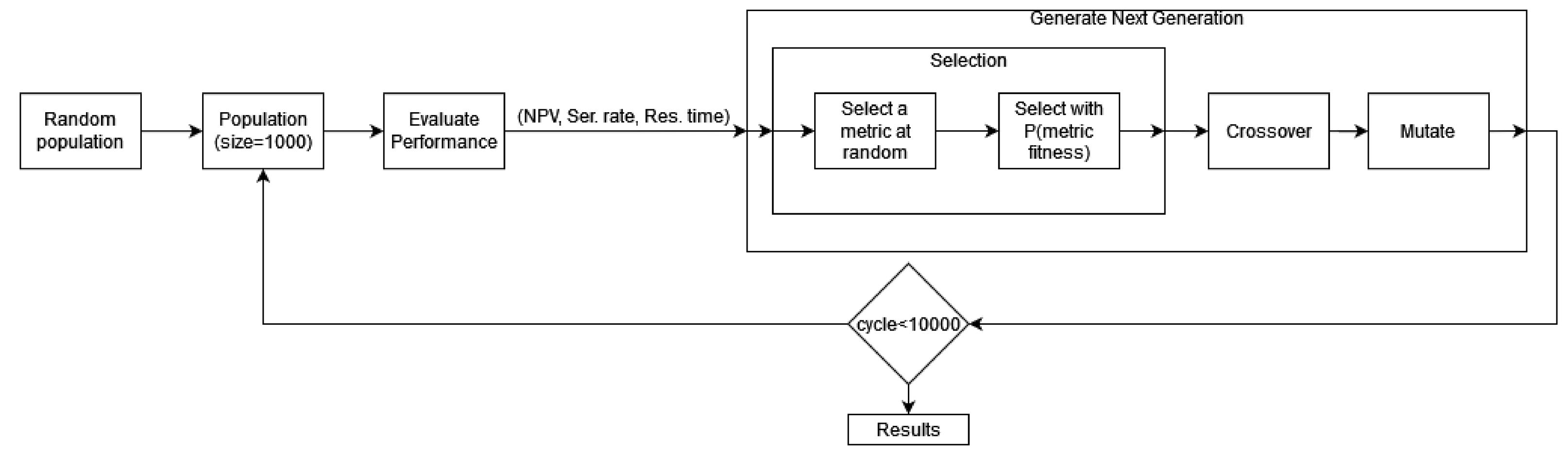
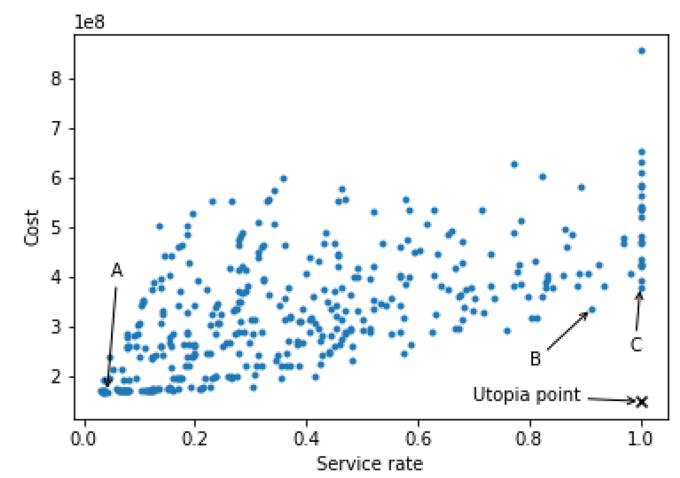
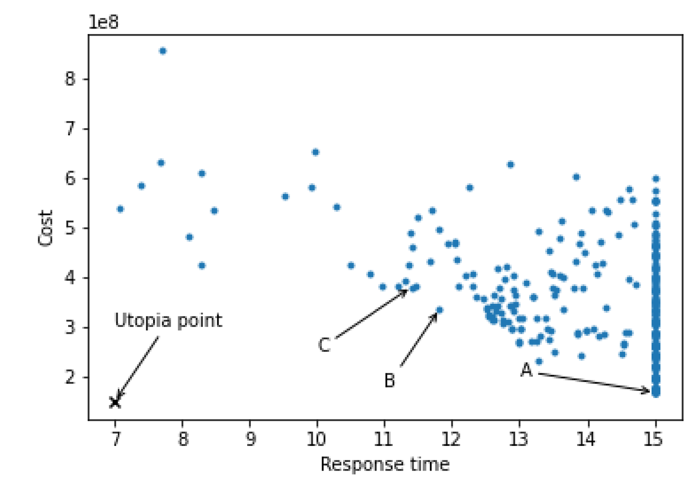


Figure 6. Architecture Optimization Overview Using Genetic Algorithm

Results/Conclusions



(a) Service Rate vs Cost



(b) Response Time vs Cost

- 3 reference architectures common for both fronts are annotated.
  - A: [5,5,5,0,3,0,0,1,1] $\longrightarrow$ Cost: $168 million, Service Rate: 4.2%, Response Time: 15 min
  - B: [5,9,15,2,7,0,0,1,2] $\longrightarrow$ Cost: $335 million, Service Rate: 91.2%, Response Time: 11.8 min
  - C: [5,17,11,2,7,0,0,2,4] $\longrightarrow$ Cost: $379 million, Service Rate: 100%, Response Time: 11.4 min
- The service rate in architecture A is too low to consider.
- Architecture C is better than Architecture B in both performance metrics (9.6% and 3.5% in service rate and response time respectively).
- Architecture B is less expensive (11.6% less).

References

[1] pyeasyga, Genetic Algorithm library in Python. https://github.com/remiomosowon/pyeasyga.