Optimization of Drone Routing for Humanitarian Applications

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Introduction

- UAV technology is almost mature
  - New applications and commercial uses
  - Increasing autonomy, new systems
  - Lower prices

- Humanitarian uses
  - Imagery (mapping, inventory, monitoring, etc.)
    - Widely used
    - Cheap and fast
    - Easy to deploy
  - Delivery (medicines, samples, emergency kits, etc.)
    - More complex
    - Risky
    - Too small to be useful

Introduction - Context

- Political
  - Conflicts
  - Mistrust from authorities
  - UAViators consortium to find solution

- Social
  - Population afraid of drones (air strikes)
  - Concerned about espionage, possible destruction of drones

- Legal
  - No proper regulations or very restrictive ones
  - Hard to fly right away with autonomous system
  - Need for special authorizations if possible

Thesis Goal

- Provide **quantitative measurements** relative to the **time gained** by using a drone on a given **inspection mission.**
  - Through the development of route optimization models

- Give NGOs' managers tools to
  - assess the usefulness of a drone for a given mission
  - evaluate the possibilities for a mission with a known UAV
  - chose the right UAV to complete a given mission

Case study & Models

Case study

- Haiti
  - Stricken by disasters regularly (+340 000 death since 2000)
  - First place where drones massively employed in humanitarian aid
- Simplified network
  - 1 base (Port-au-Prince)
  - 4 cities to visit
  - Large scale operation (+100 km radius)
- Models could be used for any other network

Models

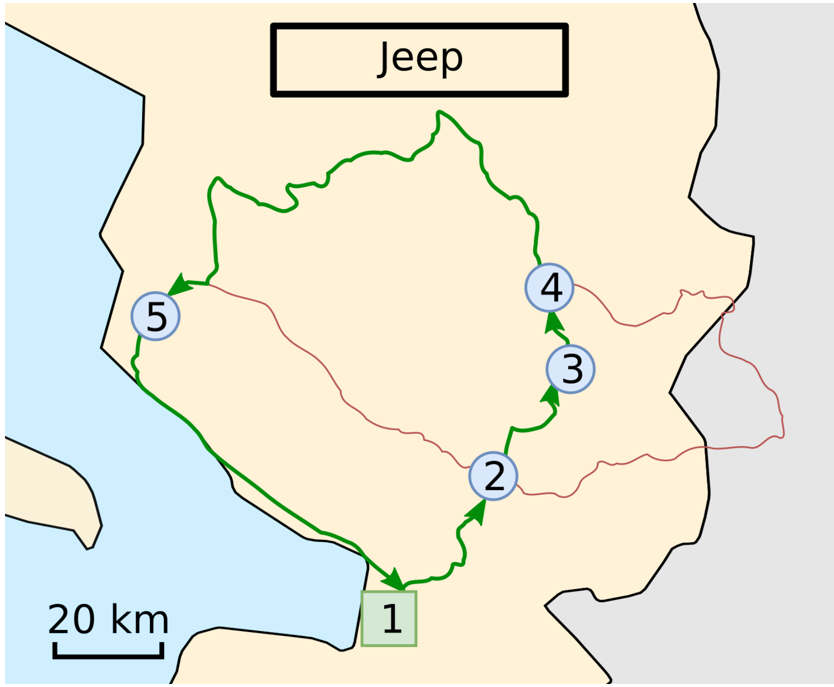
- Traveling Salesman Problem
  - Drone just needs to visit the cities
  - Most simple model, unrealistic
- Distance-constrained Vehicle Routing Problem (+ inspection)
  - Adds limitation on the drone endurance
  - Forces it to return to the base to refuel
  - Significantly increase mission time
  - (+ add time for inspection of cities)
- Capacitated General Routing Problem
  - UAV must scan the physical roads as well

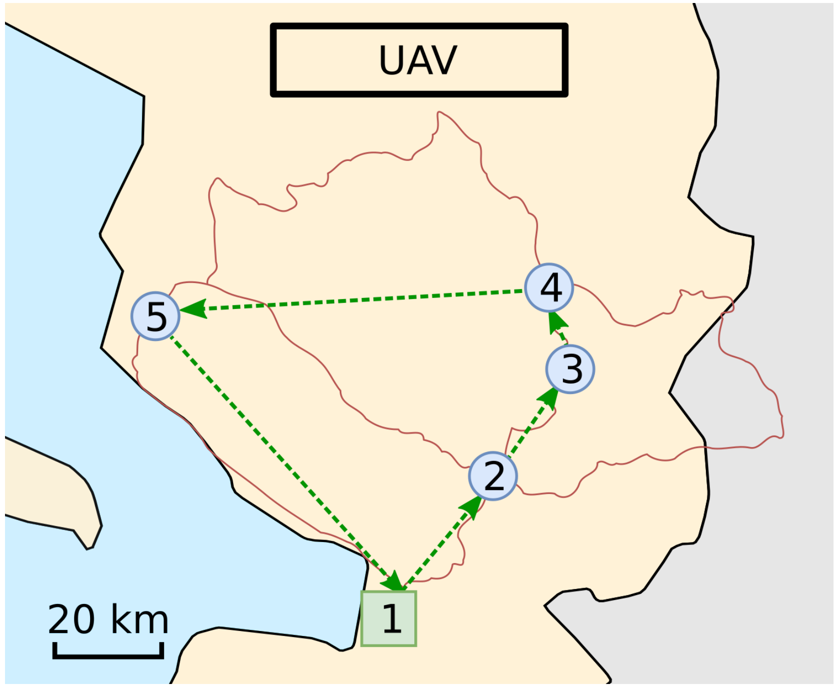
Results

TSP

- No autonomy limitation
  - Too simple, unrealistic for the UAV
  - Reasonable for the Jeep

	Jeep	UAV
Total time	9.45 h	4.6 h



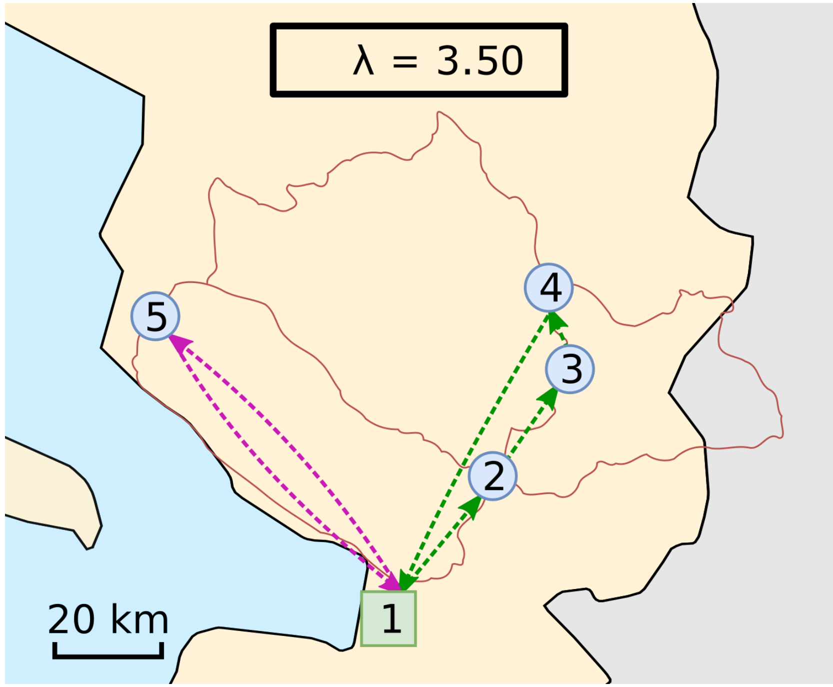


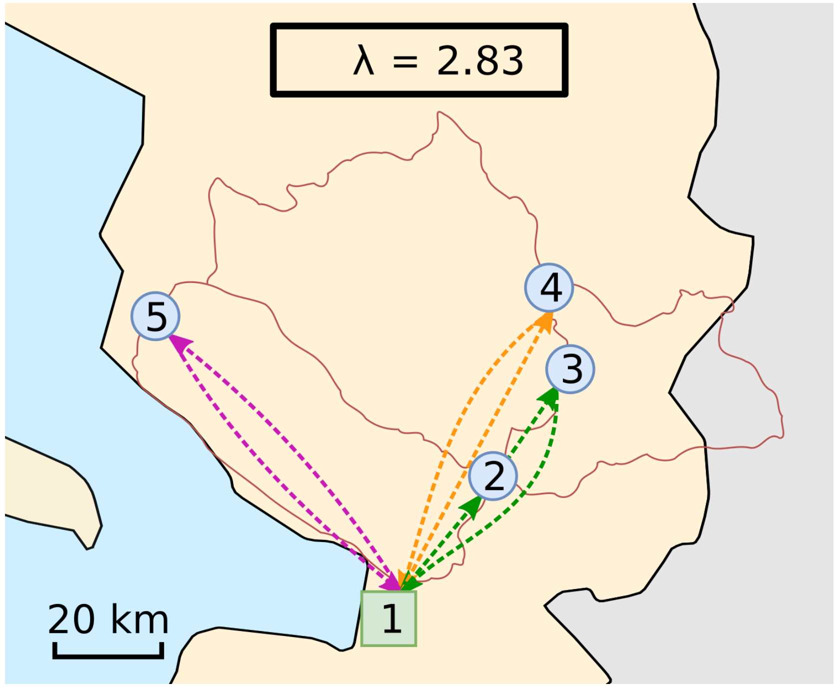
DVRP - UAV

- Limited flight-time
  - Different routes possible
  - Depends on the endurance

# Routes	1	2	3	3
Total time	4.6 h	5.95 h	7.4 h	8.15 h

Jeep: 9.45 h

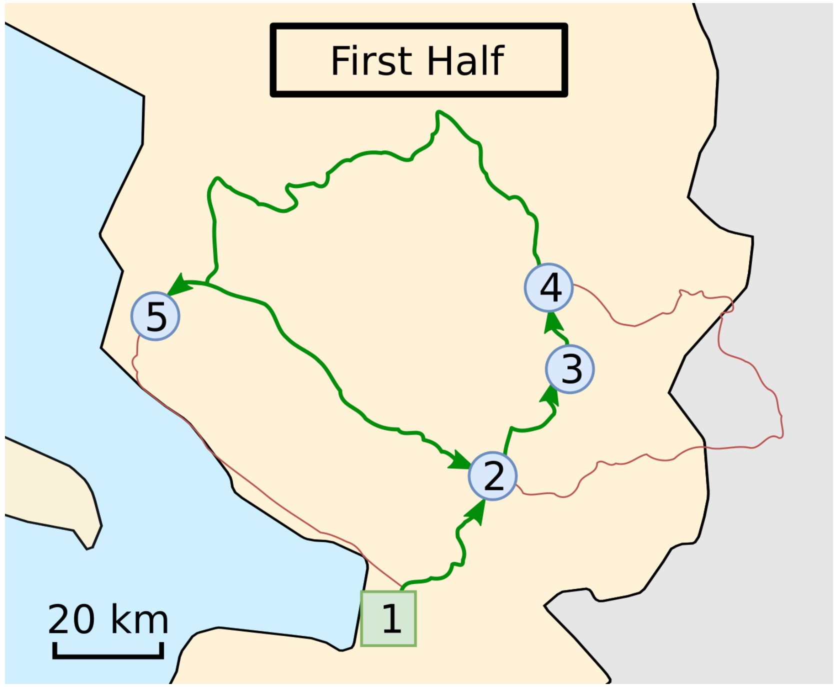


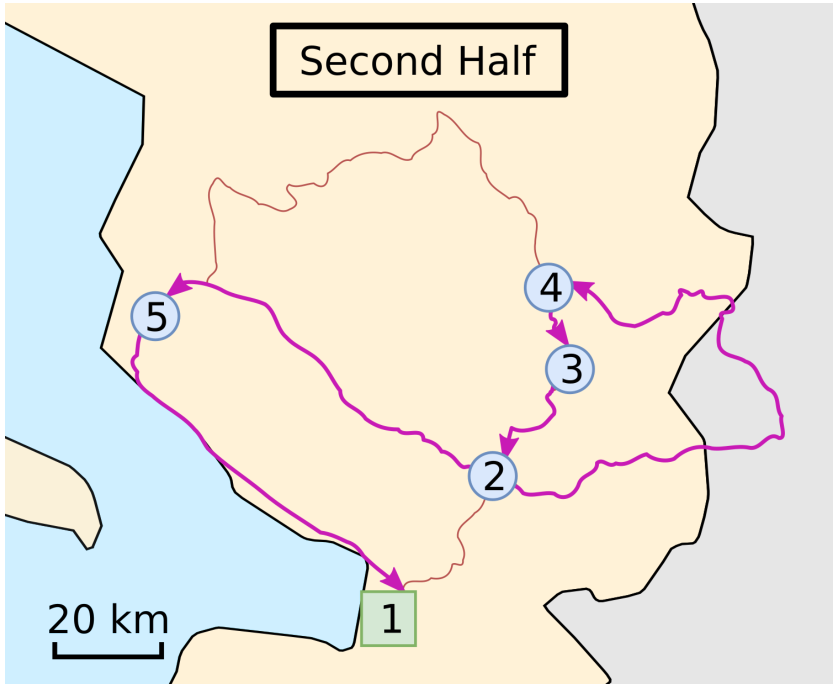


Worst case (min endurance)

CGRP- 1 Jeep

- One single Jeep
- Inefficient, many roads taken twice
- Total time: **19.84 h** !



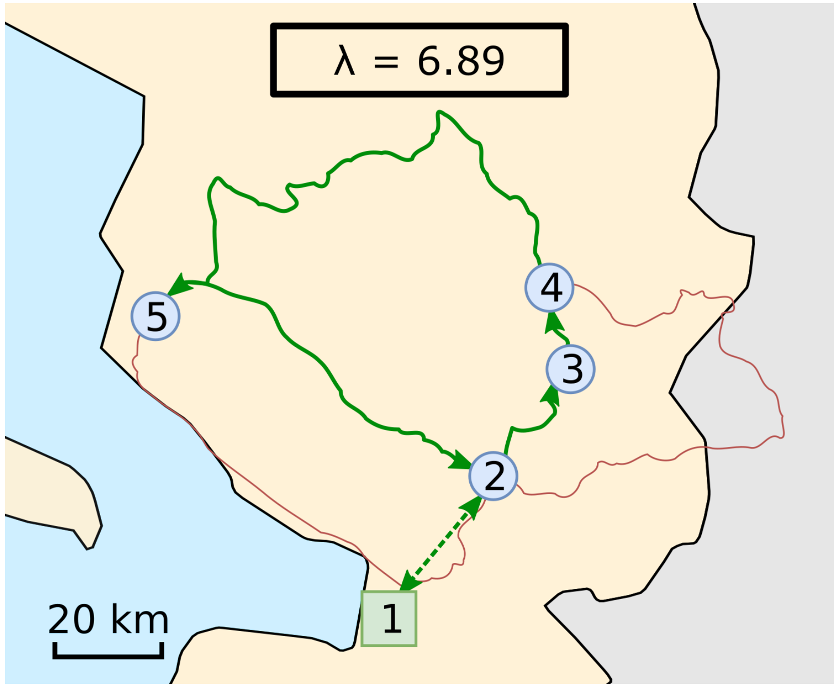


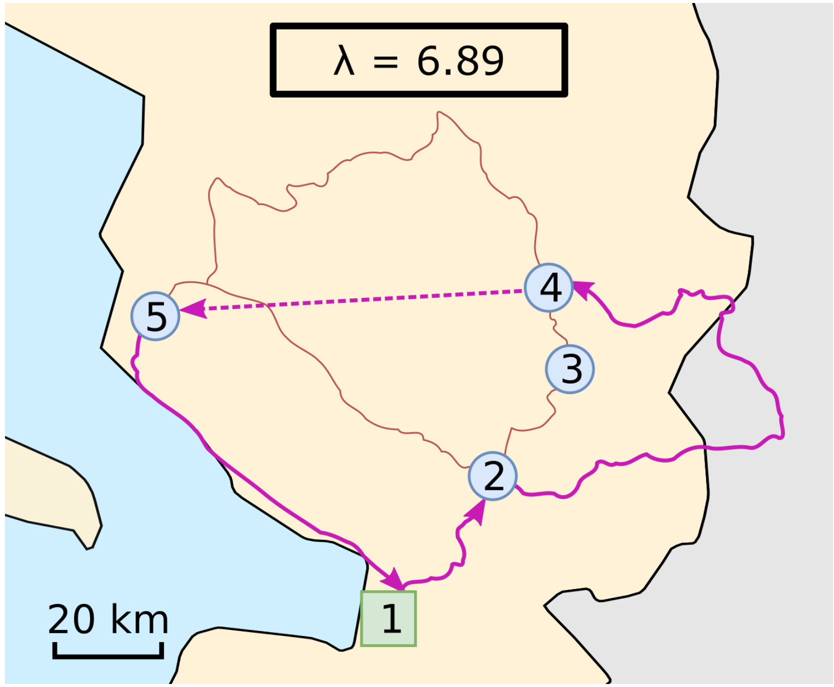
CGRP – UAV (1)

- Endurance of 6.89 h
- 1 refuel

Routes	Green	Magenta	TOTAL
Time	6.79 h	6.61 h	13.50 h

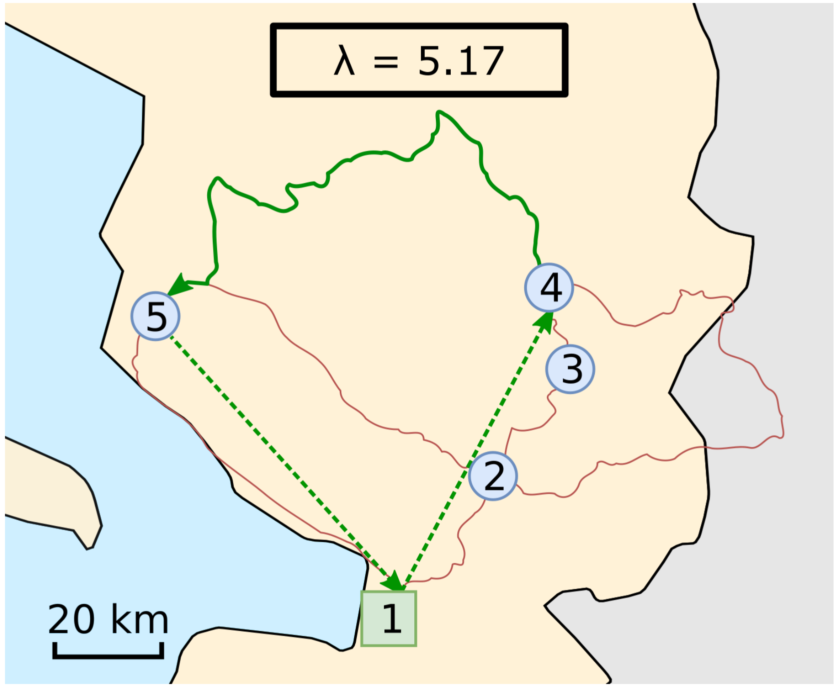
1 Jeep: 19.84 h
3 Jeeps 9.18 h max

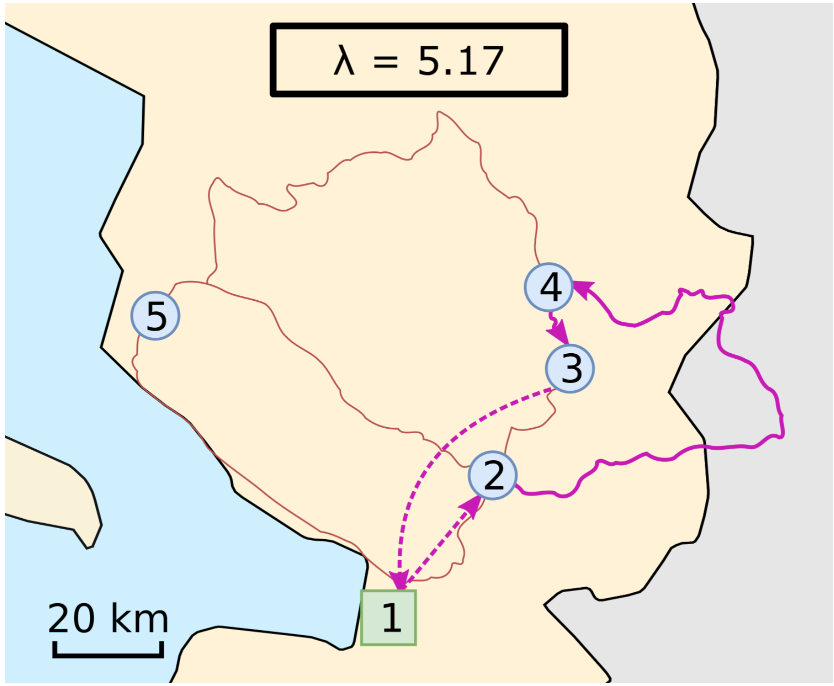




CGRP – UAV (2)

- Endurance of 5.17h
- 3 refuel
- Worst case scenario (min endurance)



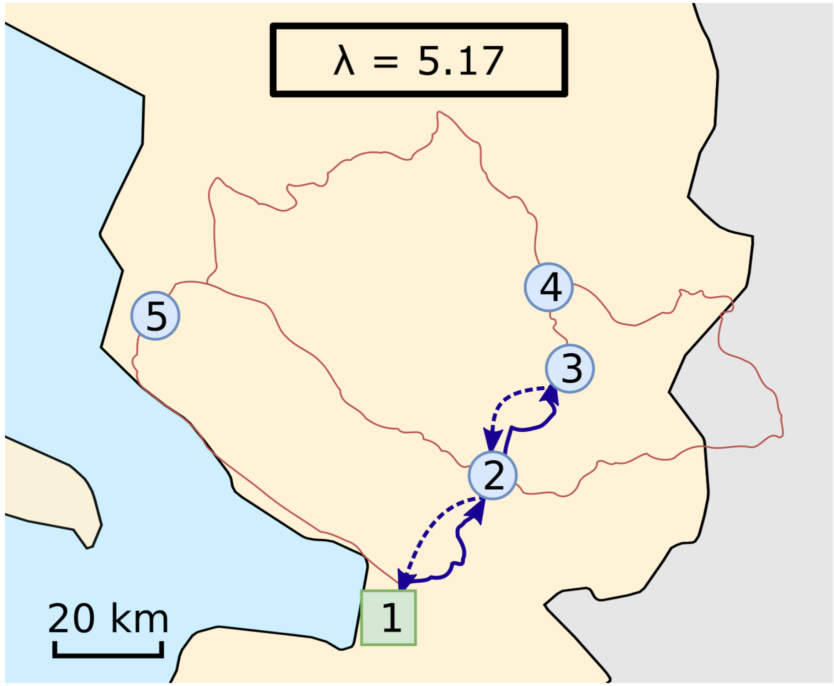


CGRP – UAV (2)

- Endurance of 5.17h
- 3 refuel
- Worst case scenario

Routes	Green	Magenta	Orange	Blue	TOTAL
Time	5.15 h	4.99 h	3.91 h	2.79 h	17.14 h

1 Jeep: 19.84 h
3 Jeeps 9.18 h max



Conclusion

Conclusion

Future work

Conclusions

- Great tool for humanitarian applications
  - Provide useful aerial imagery
    - *Bird eyes perspective*
  - Easier to mobilize than satellites or planes
    - Especially after hurricanes / tropical rains

- BUT:
  - Political/social issues
    - War zones, mistrust,…
  - Legal problems
    - Create permissive regulations
    - Entrust NGOs operators (international licenses)

Conclusions

- Drones are considerably faster than ground vehicles
  - For every mission analyzed
    - Should be verified against other networks (mountains, rural, jungle,…)
  - Time spared = lives saved

- Models should be used to determine
  - Performance of a given drone in various situations
  - Benchmark drones before buying a new one

- NGOs should invest in larger scale drones

Future work

- Extend current models
  - Target priority
  - More accurate energy consumption model
  - Optimize sub-route time instead of full mission (minimize required endurance)
- Add randomness
  - Inspection time
  - Target location and time of appearance
  - Damaged roads (re-routing)
- Add joint-optimization
  - Combine Jeep and UAV
  - Position of fuel depots or fuel trucks

Thank you

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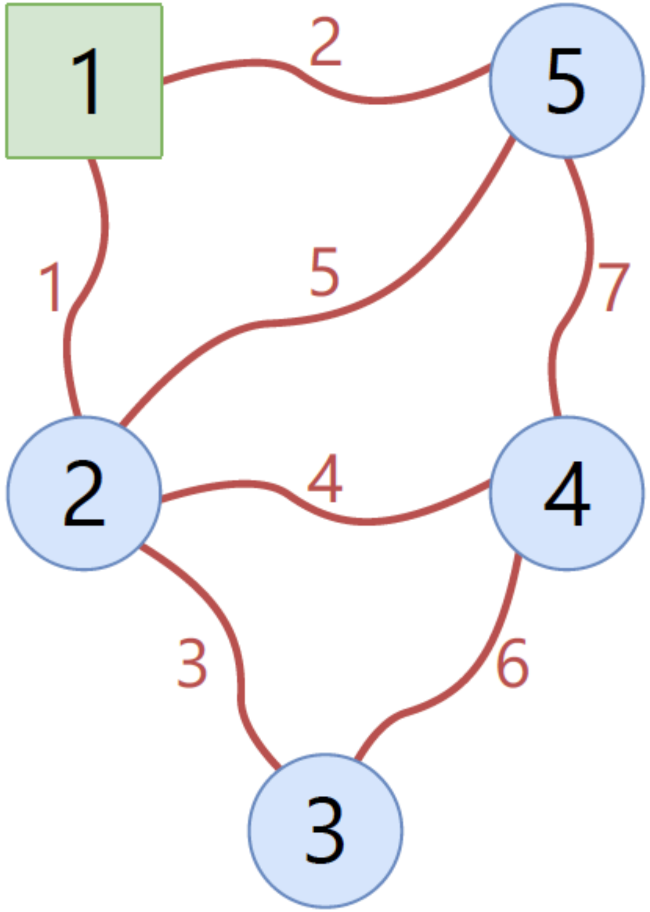
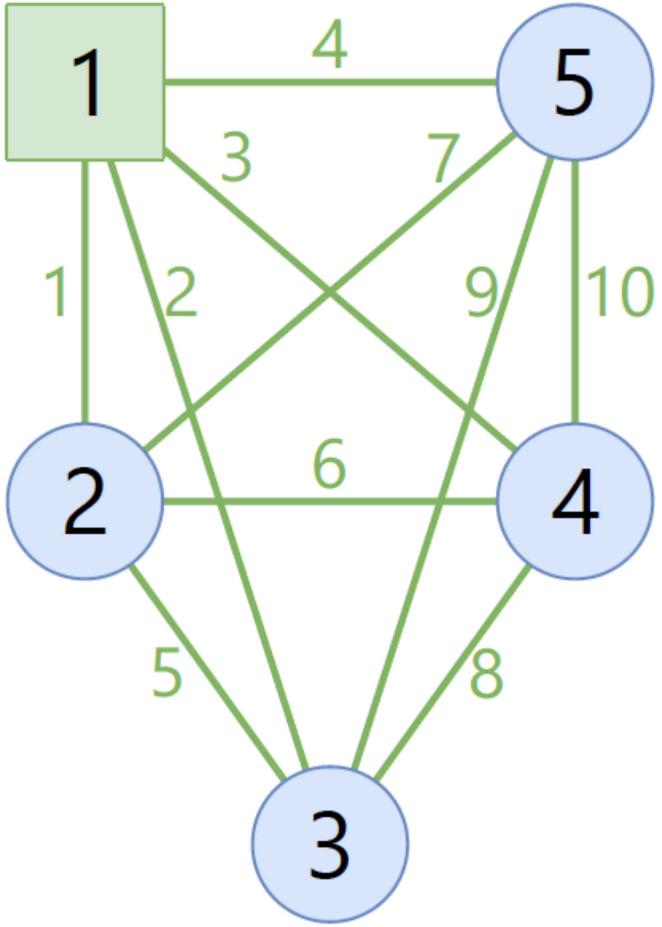
Networks

Roads



Aerial



Model - TSP

$$\min \sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} t_{ij} X_{ij} \tag{1.1a}$$

subject to:

$$\sum_{\substack{i=1 \\ i \neq j}}^{n} X_{ij} = 1 \qquad j = 1, \ldots n; \tag{1.1b}$$

$$\sum_{\substack{j=1 \\ j \neq i}}^{n} X_{ij} = 1 \qquad i = 1, \ldots n; \tag{1.1c}$$

$$U_i - U_j + n X_{ij} \leq n - 1 \qquad 2 \leq i \neq j \leq n; \tag{1.1d}$$

$$0 \leq U_i \leq n - 1 \qquad 2 \leq i \leq n; \tag{1.1e}$$

$$X_{ij} \in \{0, 1\} \qquad i, j = 1, \ldots n; \tag{1.1f}$$

$$U_i \in \mathbb{Z} \qquad i = 1, \ldots n. \tag{1.1g}$$

Model - DVRP

$$\min \left[\sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} t_{ij} X_{ij} + \sum_{j=1}^{n} \alpha X_{1j} - \alpha \right] \qquad (1.2a)$$

subject to:

$$\sum_{\substack{i=1 \\ i \neq j}}^{n} X_{ij} = 1 \qquad j = 2, \ldots, n; \qquad (1.2b)$$

$$\sum_{\substack{j=1 \\ j \neq i}}^{n} X_{ij} = 1 \qquad i = 2, \ldots, n; \qquad (1.2c)$$

$$\sum_{j=2}^{n} X_{1j} \leq k \qquad (1.2d)$$

$$\sum_{i=2}^{n} X_{i1} \leq k \qquad (1.2e)$$

$$\sum_{\substack{j=1 \\ j \neq i}}^{n} V_{ij} - \sum_{\substack{j=1 \\ j \neq i}}^{n} V_{ji} - \sum_{j=1}^{n} t_{ij} X_{ij} = 0 \qquad i = 2, \ldots, n; \qquad (1.2f)$$

$$V_{ij} \leq (\lambda - t_{j1}) X_{ij} \qquad i, j = 1, \ldots, n; \qquad (1.2g)$$

$$V_{ij} \geq (t_{1i} + t_{ij}) X_{ij} \qquad i = 2, \ldots, n\,,\ j = 1, \ldots, n; \qquad (1.2h)$$

$$V_{1i} = t_{1i} X_{1i} \qquad i = 2, \ldots, n; \qquad (1.2i)$$

$$X_{ij} \in \{0, 1\} \qquad i, j = 1, \ldots, n; \qquad (1.2j)$$

Model - CGRP

$$\min \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{p=1}^{k} t_{ij} X_{ij}^{p} \tag{1.3a}$$

subject to:

$$\sum_{m=1}^{n} X_{mi}^{p} - \sum_{m=1}^{n} X_{im}^{p} = 0 \qquad i = 1, \ldots, n\,,\ p = 1, \ldots, k; \tag{1.3b}$$

$$\sum_{p=1}^{k} \left(L_{ij}^{p} + L_{ji}^{p} \right) = d_{ij} \qquad i, j = 1, \ldots n; \tag{1.3c}$$

$$X_{ij}^{p} \geq L_{ij}^{p} \qquad i, j = 1, \ldots n\,,\ p = 1, \ldots, k; \tag{1.3d}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} \left(t_{ij} X_{ij}^{p} + e_{ij} L_{ij}^{p} \right) \leq \lambda \qquad p = 1, \ldots, k; \tag{1.3e}$$

$$\sum_{m=1}^{n} F_{im}^{p} - \sum_{m=1}^{n} F_{mi}^{p} = \sum_{j=1}^{n} L_{ij}^{p} \qquad i = 2, \ldots n\,,\ p = 1, \ldots, k; \tag{1.3f}$$

$$F_{ij}^{p} \leq n^{2} X_{ij}^{p} \qquad i, j = 1, \ldots n\,,\ p = 1, \ldots, k; \tag{1.3g}$$

$$F_{ij}^{p} \geq 0; \tag{1.3h}$$

$$X_{ij}^{p},\ L_{ij}^{p} \in \{0, 1\} \qquad i, j = 1, \ldots n\,,\ p = 1, \ldots, k; \tag{1.3i}$$