Operations Research
Final Presentation

Group P

Optimizing The Efficiency of Fire Rescue Operations

STUDENT

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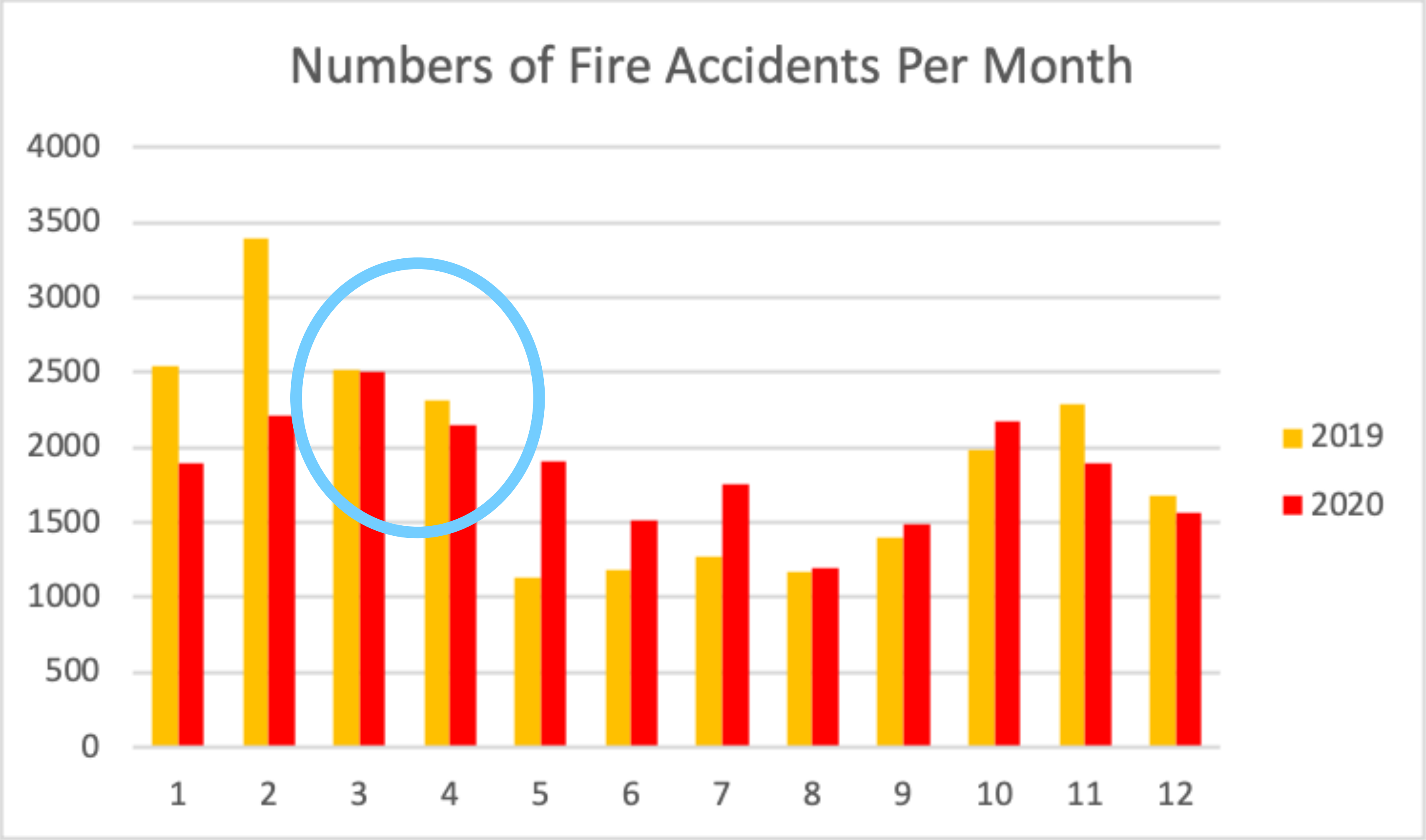
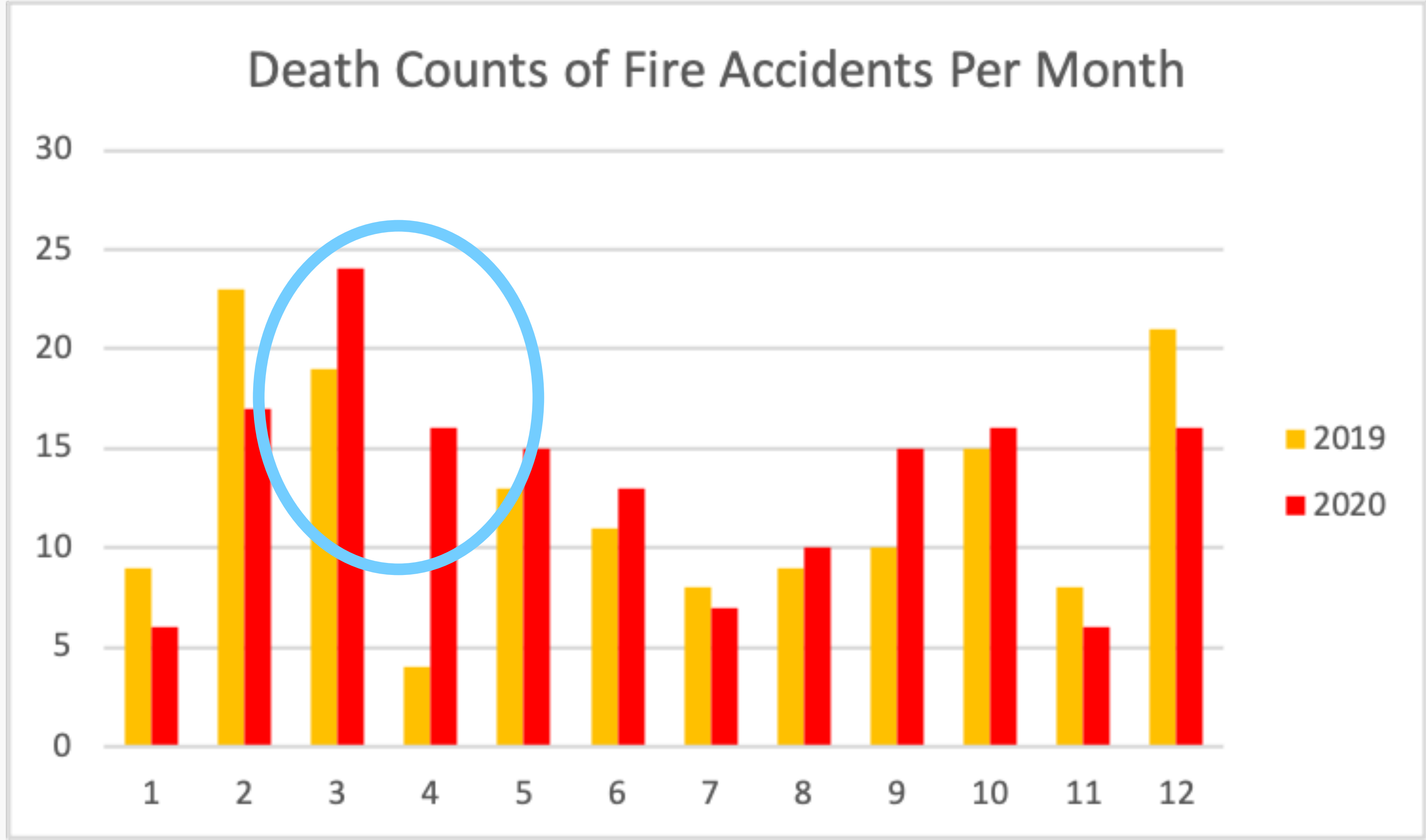
I Motivation

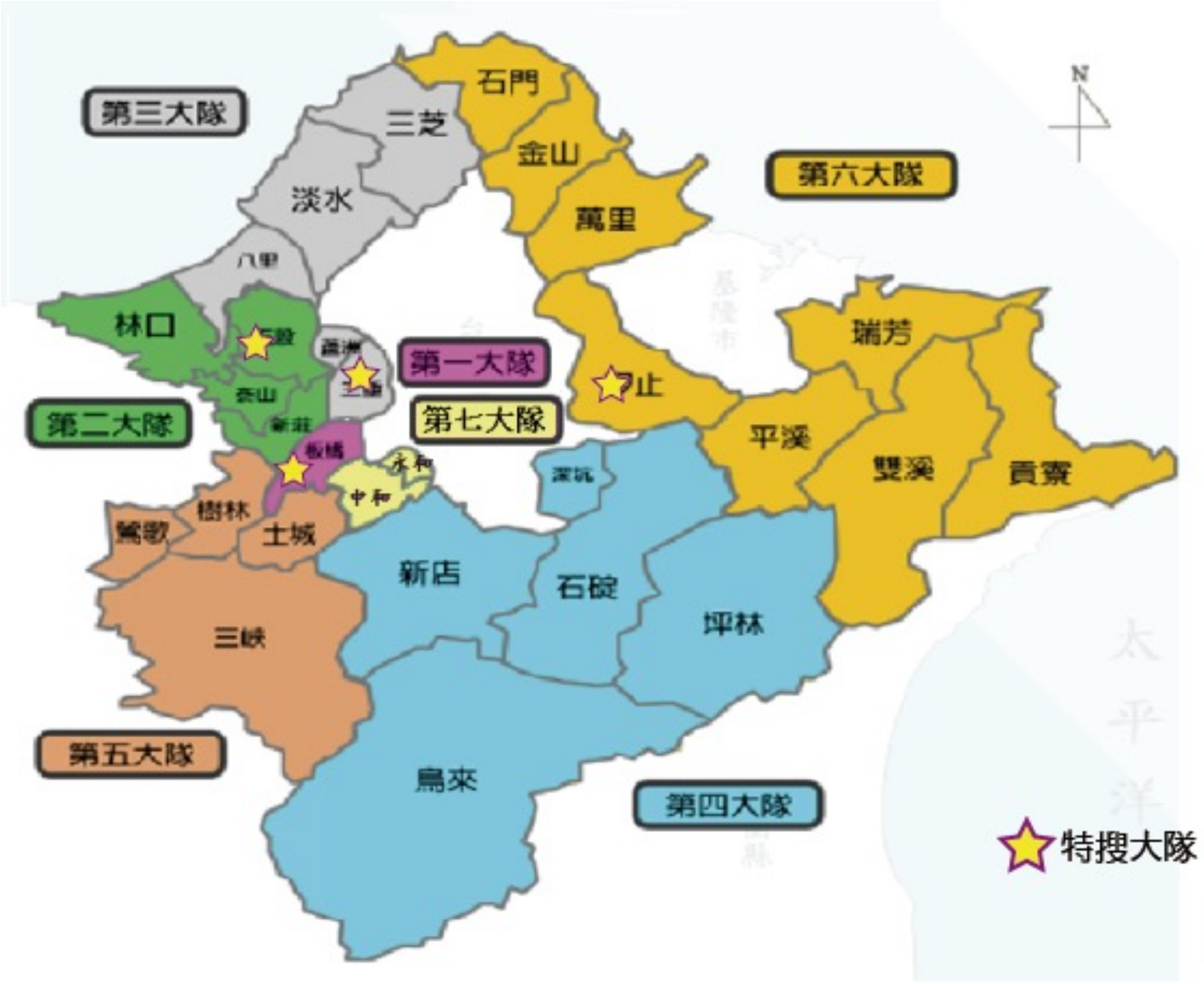
A Case Study of Taiwan

- Lack of fire stations?
- Inefficiency in rescue work assignments?





- Timely arrival of firefighting personnel and material resources directly impacts the number of lives saved during a fire incident.
- Currently, the rescue work in Taiwan is divided by location, i.e. municipal districts.
- There might be a more efficient way.



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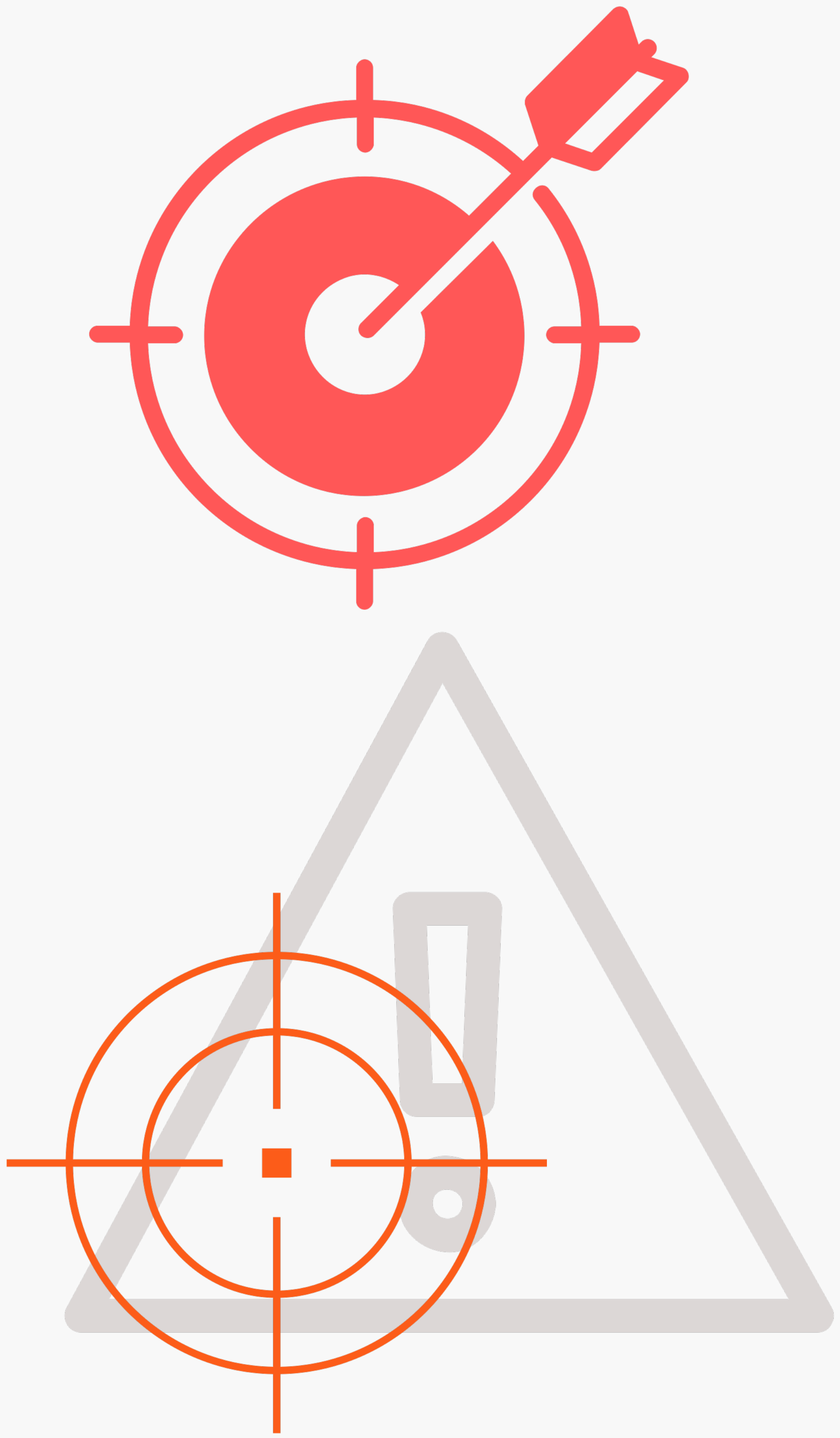
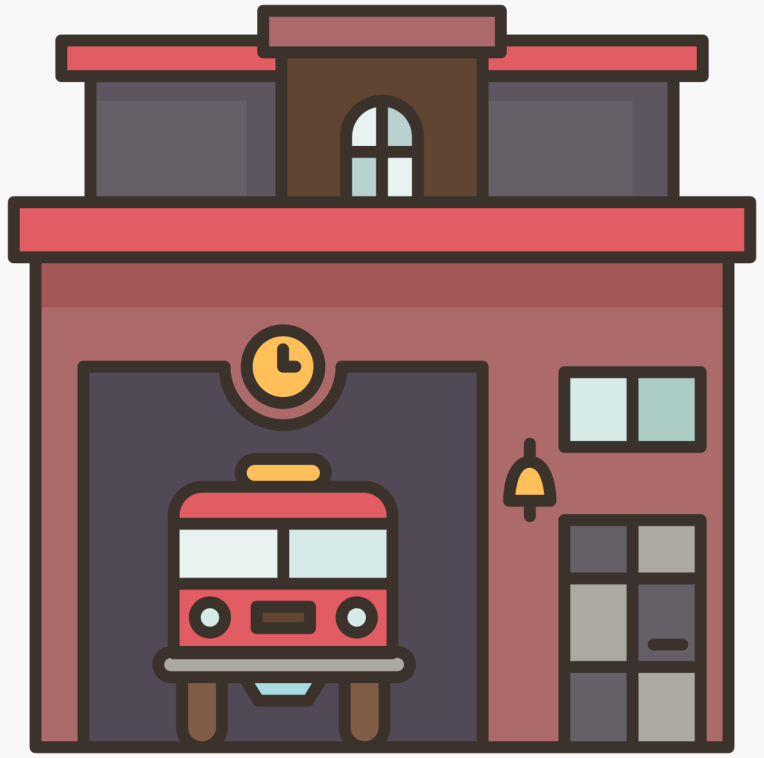


Problem Description

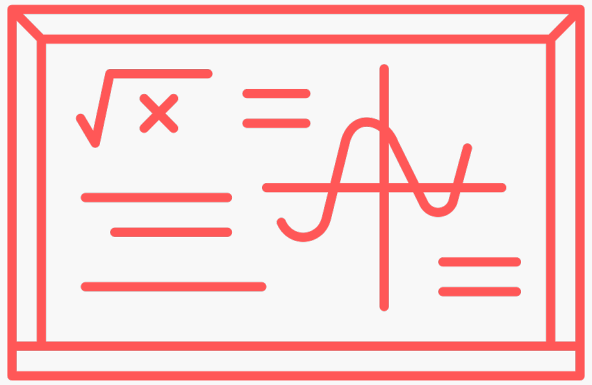
We would like to know:

- How do we optimize the assignment of firefighting resources?
  - How much improvement in efficiency can we gain if we assign firefighting resources (the squad and the ambulances) relaxing the brigade constraints?
  - Which areas do we have the most accidents that may not be rescued within a limited time?
- Where should we build new fire stations given new budget?

Therefore, we formulated two models to deal with these problems respectively.



Operations Research Model- Model 1



Model I: Minimizing The Distance From The Fire Station to The Site of Accident

- Objective: Minimize the distance between the site of accident and the fire stations that sent squads and ambulances to the spot
- Decisions:
  - For all fire stations, whether the squad should be sent to the scene of accident
  - How many ambulances should be sent from each fire station
- Constraints:
  - Fire rescue and ambulance requirements must be satisfied
  - Fires saved and ambulances sent should not exceed their respective daily quota

- # Decision variables

a_{ij} : whether to send squad in fire station i to accident j, $i \in I, j \in J$

x_{ij} : amount of ambulance for fire station i to send to accident j, $\forall i \in I, j \in J$

- # Parameters

$$
\begin{aligned}
I &: \text{the set of fire stations} \\
J &: \text{the set of accident locations} \\
Q^F &: \text{fire rescue quota per day} \\
Q^A &: \text{ambulance quota per day} \\
H_{ij} &: \text{distance between fire station } i \text{ and accident location } j \\
R_j^F &: \text{requirement of fire quota for accident } j, j \in J \\
R_j^A &: \text{requirement of ambulance quota for accident } j, j \in J \\
B_{ij} &: \text{whether fire station } i \text{ can go to rescue accident } j, i \in I, j \in J \\
A_{jd} &: \text{whether accident } j \text{ happens on day } d, j \in J, d \in D \\
M &: \text{should be upper bound} \\
F &: \frac{1}{|I|\,|J|\,H} \text{ where H is } \max_{(i,j)\,\in\, I \times J} H_{ij}
\end{aligned}
$$

- **Objective function**

$$\min \boxed{\sum_{i\in I}\sum_{j\in J} a_{ij}H_{ij}} + \boxed{\sum_{i\in I}\sum_{j\in J} x_{ij}H_{ij}}$$

• Constraints for current situation

$$\sum_{j\in J} a_{ij} A_{jd} \le Q^F \quad \forall i \in I, d \in D \tag{1}$$

$$\sum_{j\in J} x_{ij} A_{jd} \le Q^A \quad \forall i \in I, d \in D \tag{2}$$

$$\sum_{i} a_{ij} \ge R_j^F \quad \forall j \in J \tag{3}$$

$$\sum_{i} x_{ij} \ge R_j^A \quad \forall j \in J \tag{4}$$

$$a_{ij} \le B_{ij} \quad \forall i \in I, j \in J \tag{5}$$

$$x_{ij} \le R_j^A B_{ij} \quad \forall i \in I, j \in J \tag{6}$$

$$a_{ij} \in \{0, 1\} \tag{7}$$

$$x_{ij} \ge 0, \quad x_{ij} \in \mathbb{Z} \tag{8}$$

(1) Daily saved fires should not exceed their respective quota for each station.

(2) Daily sent ambulances should not exceed their respective quota for each station.

(3) The fire rescue requirement must be satisfied.

(4) The ambulance requirement must be satisfied.

(5) The brigade rescue constraint for the squad.

(6) The brigade rescue constraint for ambulances.

• Constraints for our relaxed model

$$\sum_{j\in J} a_{ij}A_{jd} \leq Q^F \quad \forall i \in I, d \in D \tag{1}$$

$$\sum_{j\in J} x_{ij}A_{jd} \leq Q^A \quad \forall i \in I, d \in D \tag{2}$$

$$\sum_{i} a_{ij} \geq R_j^F \quad \forall j \in J \tag{3}$$

$$\sum_{i} x_{ij} \geq R_j^A \quad \forall j \in J \tag{4}$$

$$\cancel{a_{ij} \leq B_{ij} \quad \forall i \in I, j \in J} \tag{5}$$

$$\cancel{x_{ij} \leq R_j^A B_{ij} \quad \forall i \in I, j \in J} \tag{6}$$

$$a_{ij} \in \{0,1\} \tag{7}$$

$$x_{ij} \geq 0, \quad x_{ij} \in \mathbb{Z} \tag{8}$$

(1) Daily saved fires should not exceed their respective quota for each station.
(2) Daily sent ambulances should not exceed their respective quota for each station.
(3) The fire rescue requirement must be satisfied.
(4) The ambulance requirement must be satisfied.

Operations Research Model- Model 2

Model II: Maximizing the Number of Accidents Rescued Within a Limited Time

- Objective: Maximize the number of accidents rescued within a limited time.
- Decisions:
  - For all fire stations, whether the squad should be sent to the accident spot
- Constraints:
  - Fire rescue requirements must be satisfied
  - Fires saved and ambulances sent should not exceed their respective daily quota
  - The squad sent to rescue should be in the same brigade as the accident spot

- **Objective function**

$$\max \boxed{\sum_{j \in J} s_j} - F \boxed{\sum_{i \in I} \sum_{j \in J} a_{ij} H_{ij}}$$

• Constraints

$$a_{ij}H_{ij} \leq P + M(1 - y_{ij}) \quad \forall i \in I, j \in J \tag{9}$$

$$s_j \leq \sum_{i \in I} y_{ij} \quad \forall j \in J \tag{10}$$

$$\sum_{j \in J} a_{ij}A_{jd} \leq Q^F \quad \forall i \in I, d \in D \tag{11}$$

$$\sum_{i \in I} a_{ij} \geq R_j^F \quad \forall j \in J \tag{12}$$

$$a_{ij} \leq B_{ij} \quad \forall i \in I, j \in J \tag{13}$$

$$a_{ij} \in \{0, 1\} \quad \forall i \in I, j \in J \tag{14}$$

$$y_{ij} \in \{0, 1\} \quad \forall i \in I, j \in J \tag{15}$$

$$s_j \in \{0, 1\} \quad \forall j \in J \tag{16}$$

(9) The distance to the area of the rescue must be less or equal to the limited distance P

(10) For each fire station that rescues the incident site, if one pair meets the distance constraint, the incident will contribute to the objective function

(11) Daily saved fires should not exceed their respective quota for each station

(12) The fire rescue requirement must be satisfied.

(13) Brigade rescue constraint for the squad

Data Collection and Preprocessing

IV Data Collection & Preprocessing

Model Focus:

- Greater Taipei Area
- Taoyuan City

Between year 2018 and 2020.

Data Sources (Provided by Taiwanese Government)

Fire incident cases

Fire station locations

Townships and municipalities map

Data preprocessing

- Fixing missing values
- Dealing with problematic data
- Adding some columns needed based on operations on raw data

	A	B	C	D	E
1	name	location	wgs84aX	wgs84aY	cluster
2	第一大隊部	基隆市信義區信二路299號	121.7445	25.13578	1
3	仁愛分隊	仁愛區成功一路86號	121.7379	25.1275	1
4	信二分隊	中正區信二路299號	121.7462	25.13109	1
5	中正分隊	中正區環港街100號	121.7933	25.14024	1

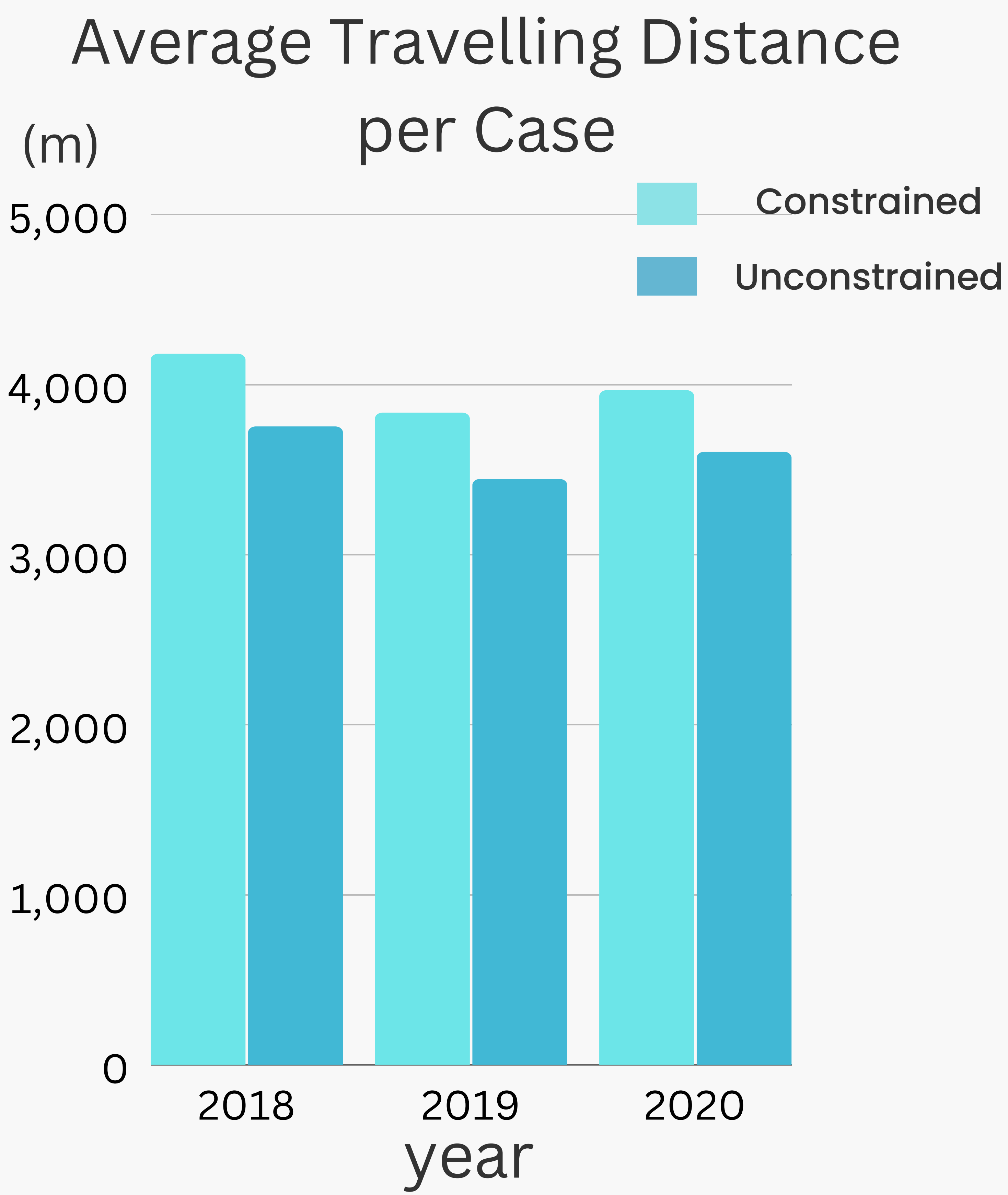
Processed station location data⬆

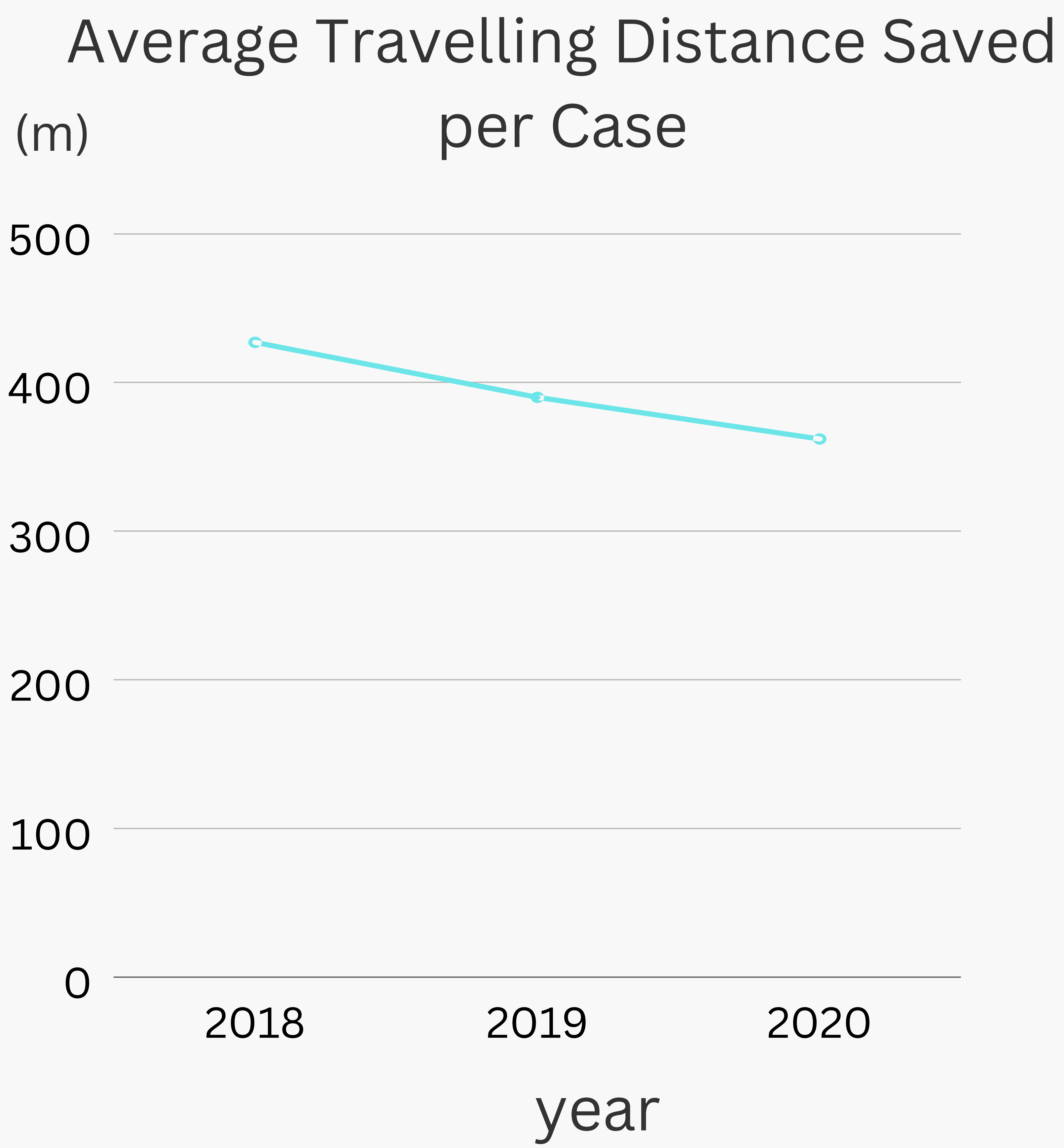
Processed fire incident location data⬇

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	city	district	street	id	notified_time	arrive_time	time_elaps	reason	death	injured	ambulance	fire_reqr	day_happe	cluster	wgs84aX	wgs84aY
2	新北市	八里區	文昌五街	H18A01A	2018/1/1 00:12	2018/1/1 00:16	4	其他-雜草、垃圾	0	0	0	1	1	3	121.4104	25.15427
3	新北市	淡水區	大同路	H18A01A	2018/1/1 00:34	2018/1/1 00:43	9	玩火-打火機	0	0	0	1	1	3	121.4637	25.14083
4	新北市	板橋區	中山路二	H18A01B	2018/1/1 01:09	2018/1/1 01:16	7	其他-雜草、垃圾	0	0	0	1	1	1	121.4789	25.01844
5	新北市	五股區	芳洲六路	H18A01E	2018/1/1 04:03	2018/1/1 04:11	8	其他-雜草、垃圾	0	0	0	1	1	2	121.4458	25.0871
6	新北市	瑞芳區	三爪子坑	H18A01M	2018/1/1 12:23	2018/1/1 12:30	7	電氣因素(不含車輛)-短路	0	0	0	1	1	6	121.8116	25.10736

ANALYSIS OF FIRST MODEL

- How much improvement in efficiency can we gain if we assign firefighting resources (the squad and the ambulances) relaxing the brigade constraints?
- Let's look at exemplary results of Taoyuan.


Average Travelling Distance
per Case
(m)
Constrained
Unconstrained
5,000
4,000
3,000
2,000
1,000
0
2018
2019
2020
year


Average Travelling Distance Saved
per Case
(m)
500
400
300
200
100
0
2018
2019
2020
year

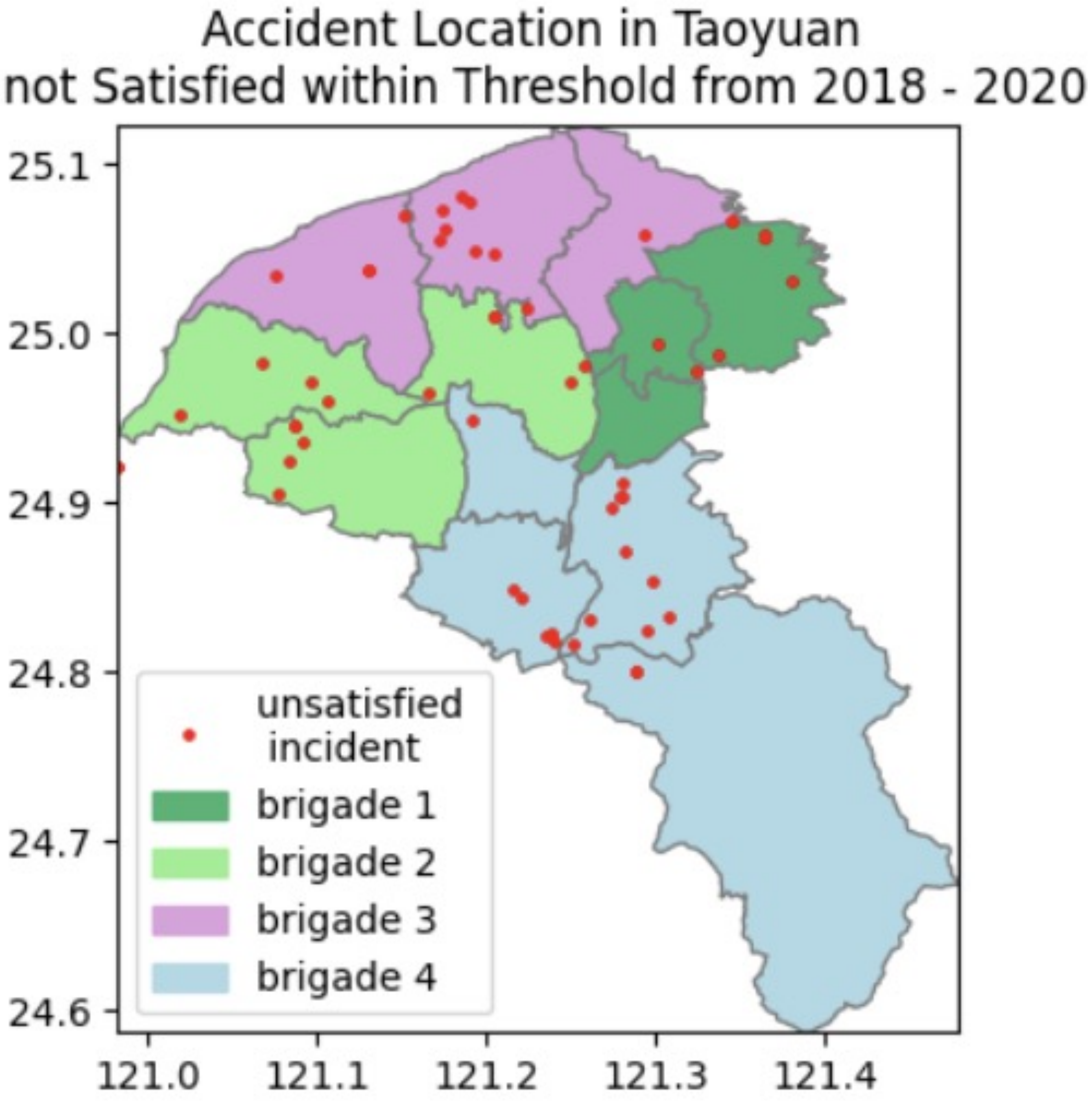
ANALYSIS OF SECOND MODEL

- Where do accidents not rescued within a limited time happen?
- Where should we build new fire stations given the budget?
- Let's revisit the results of Taoyuan.

Where are accidents not rescued within a limited time (7 min)?

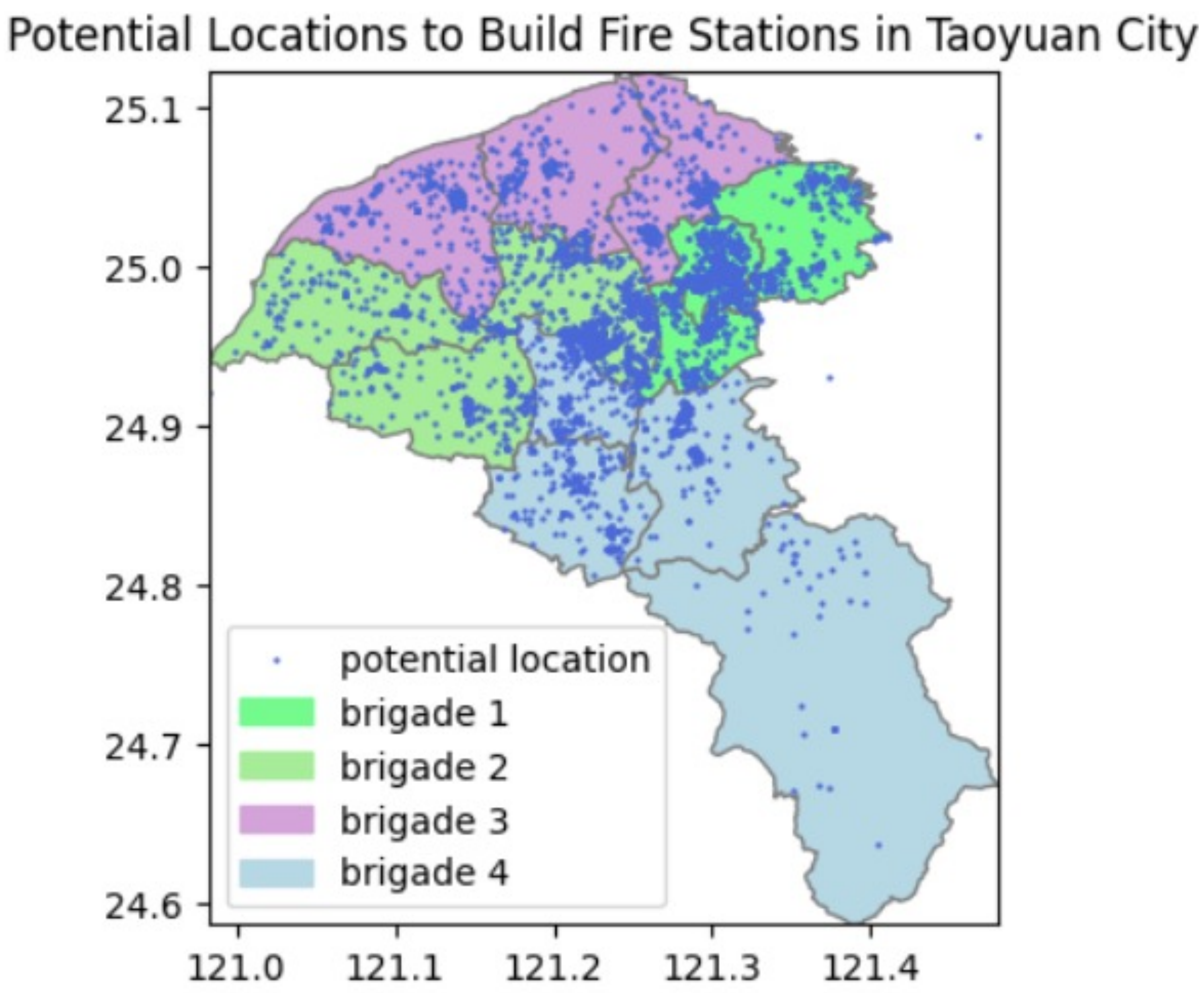
Brigade	Not Satisfied Accidents	Percentage (%)
1	16	34%
2	6	13%
3	13	28%
4	12	26%

47 vs. 2000+ (Real World, 10 min)



Where should we build the new locations given the budget?

- Using current roads as naive candidates

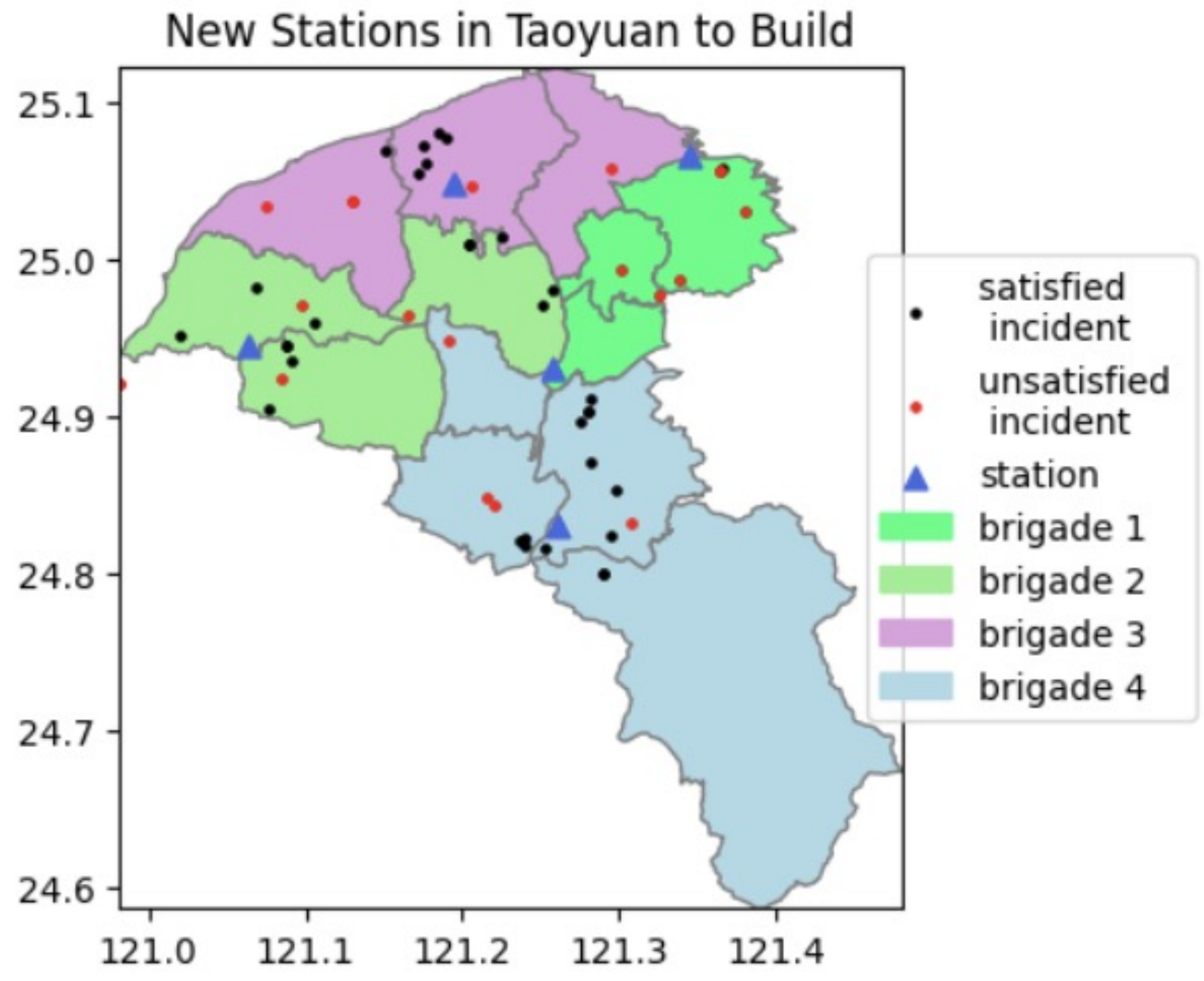


Where should we build the new locations given the budget?

- Modification and re-running of the second model
- Maximize the number of accidents rescued within 7 min (that failed previously)
- Budget Suggestion: 250M NTD (3% of the military budget)
- 5 new stations, each assumed to cost 50M NTD.

Where should we build the new locations given the budget?

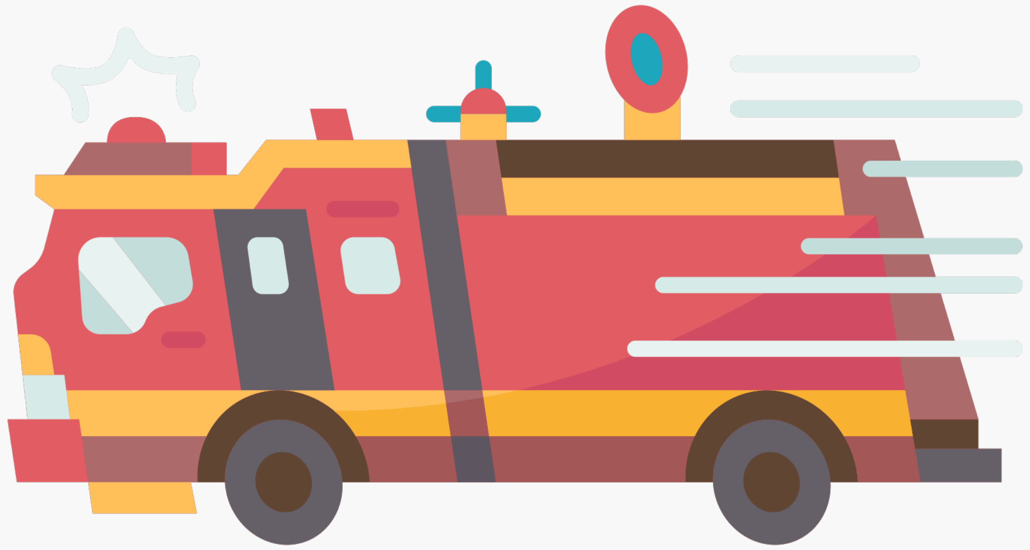
Brigade	Not Satisfied before	Additionaly Satisfied	Percentage (%)
1	16	11	69%
2	6	1	17%
3	13	9	69%
4	12	7	58%
Total	47	28	60%



Conclusion & Future Development

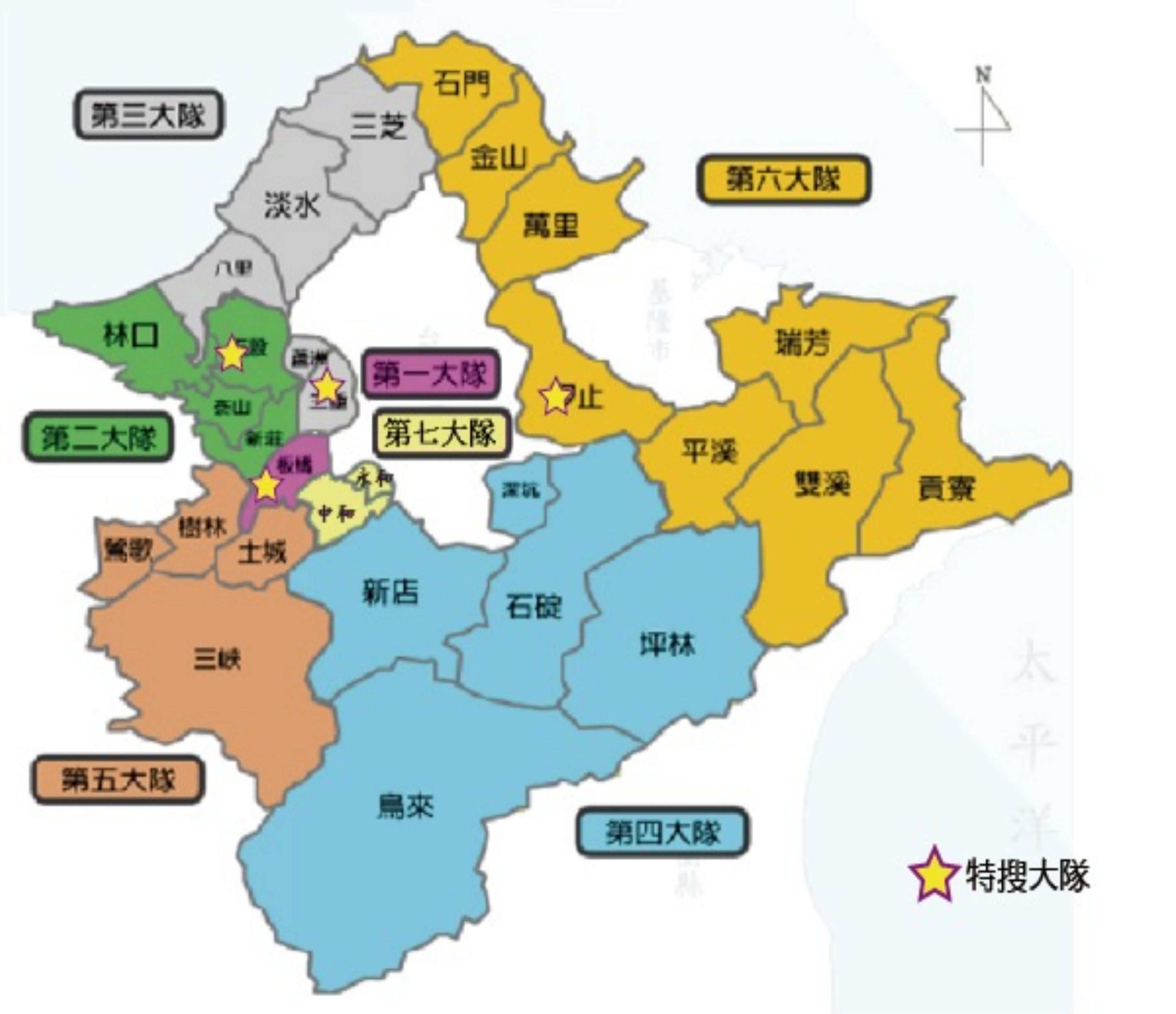
Plans to optimize firefighting operations

- By relaxing the constraints of the brigades, provides improved results for the year 2018-2020, which in turn saves 22 seconds per accident on average and a total of 9 hours.
- Identifies and optimizes the locations where accidents that were not handled within a limited amount of time, lowering from current 2000+ cases to 47 in Taoyuan.
- Identifies the optimal locations to build new stations.



VII Further Development- The Model for Strategic issues

From the strategic perspective, another useful work could be the reclassification of brigades.



The objective is to minimize the following function:

$$\min \sum_{i \in I} \sum_{j \in J} z_{ji} H_{ji}$$

subject to the following constraints:

$$\sum_{b \in B} \sum_{i \in I} a_{ab} s_{ib} z_{ji} \geq 1 \quad \forall j \in J \tag{17}$$

$$\sum_{b \in B} d_{db} = 1 \quad \forall d \in D \tag{18}$$

$$\sum_{b \in B} \sum_{d \in D} F_{id} d_{db} s_{ib} = 1 \quad \forall i \in I \tag{19}$$

$$\sum_{b \in B} \sum_{d \in D} K_{id} d_{db} a_{ib} = 1 \quad \forall i \in J \tag{20}$$

$$z_{ji} \in \{0,1\}, \quad a_{jb} \in \{0,1\} \quad \forall i \in I, \quad \forall j \in J, \quad \forall b \in B \tag{21}$$

$$s_{ib} \in \{0,1\}, \quad d_{db} \in \{0,1\} \quad \forall i \in I, \quad \forall b \in B, \quad \forall d \in D \tag{22}$$

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Thank you!