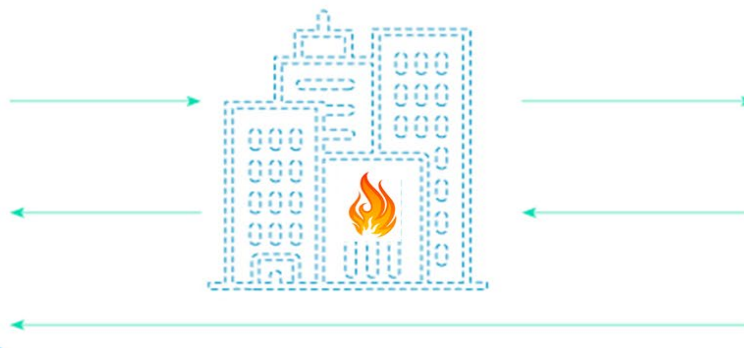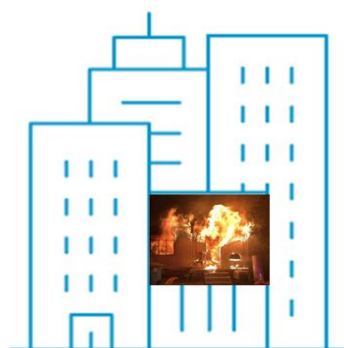# Firefighters' safety in fire: Exploring safety awareness and decision-making aiming at multiple firefighting operations

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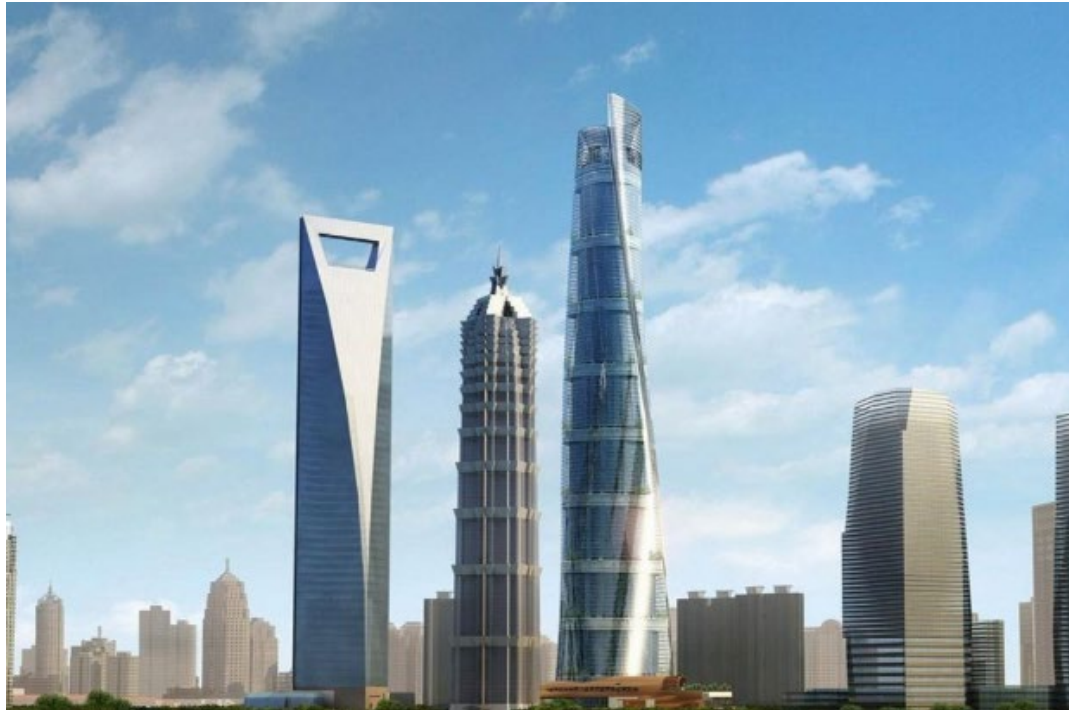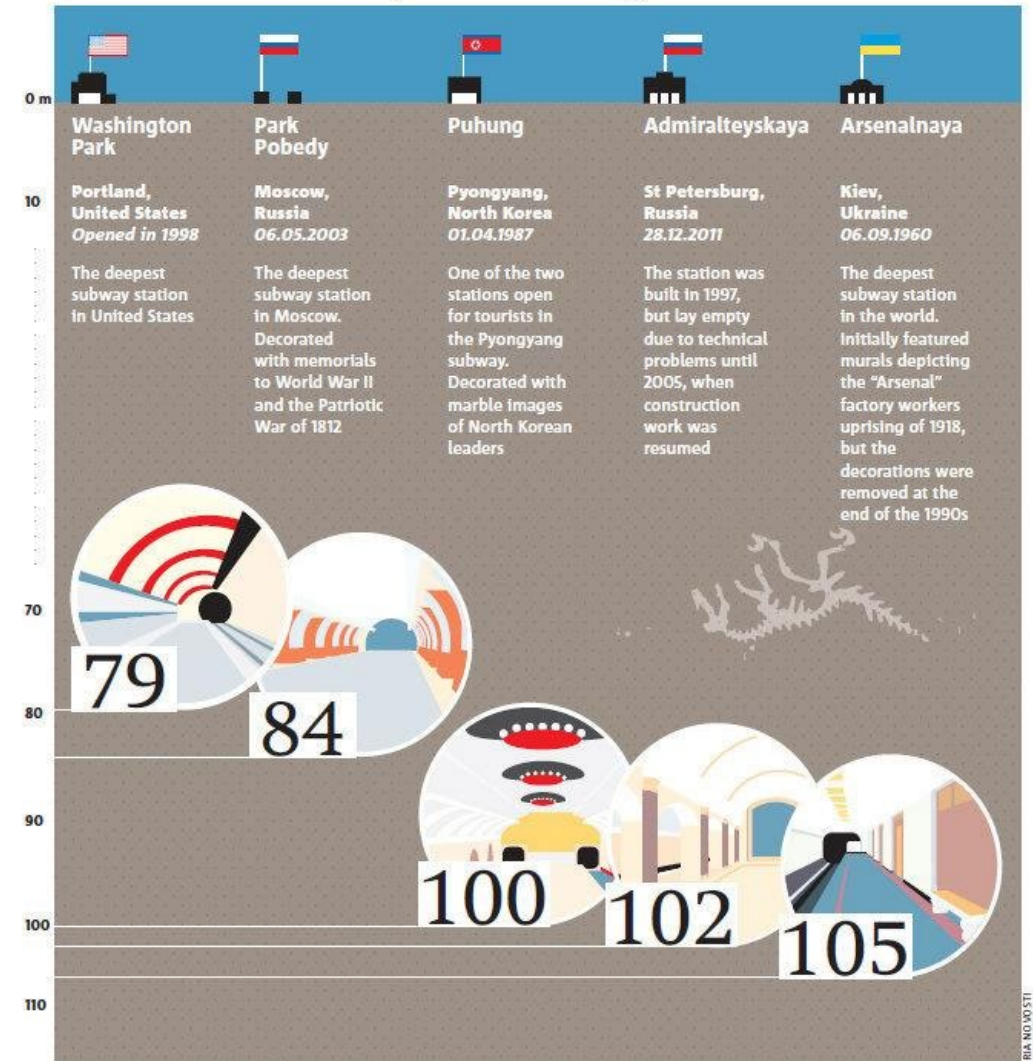
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Outline

1. Background

2. Previous work on firefighters: SFT

3. Survey and results of firefighters

4. Classification of firefighters based on decision-making preferences

Fire accidents

- Ascending floors

- Deeper underground spaces

- High density of occupants

The world's deepest subway stations

Washington Park	Park Pobedy	Puhung	Admiralteyskaya	Arsenalnaya
Portland, United States Opened in 1998	Moscow, Russia 06.05.2003	Pyongyang, North Korea 01.04.1987	St Petersburg, Russia 28.12.2011	Kiev, Ukraine 06.09.1960
The deepest subway station in United States	The deepest subway station in Moscow. Decorated with memorials to World War II and the Patriotic War of 1812	One of the two stations open for tourists in the Pyongyang subway. Decorated with marble images of North Korean leaders	The station was built in 1997, but lay empty due to technical problems until 2005, when construction work was resumed	The deepest subway station in the world. Initially featured murals depicting the "Arsenal" factory workers uprising of 1918, but the decorations were removed at the end of the 1990s

79 84 100 102 105

Firefighters' safety issues

Mini-storage fire in Hong Kong, 2016

- There was no occupant injury
- **2 firefighters were dead**
- **11 firefighters were injured**

Firefighters' safety issues

City library in Porterville, California, 2020

Two firefighters were dead when battling a fire

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Safe firefighting time (SFT)

Safe firefighting time: firefighters experience no instantaneous injury or no long-term health issue, either physical or mental
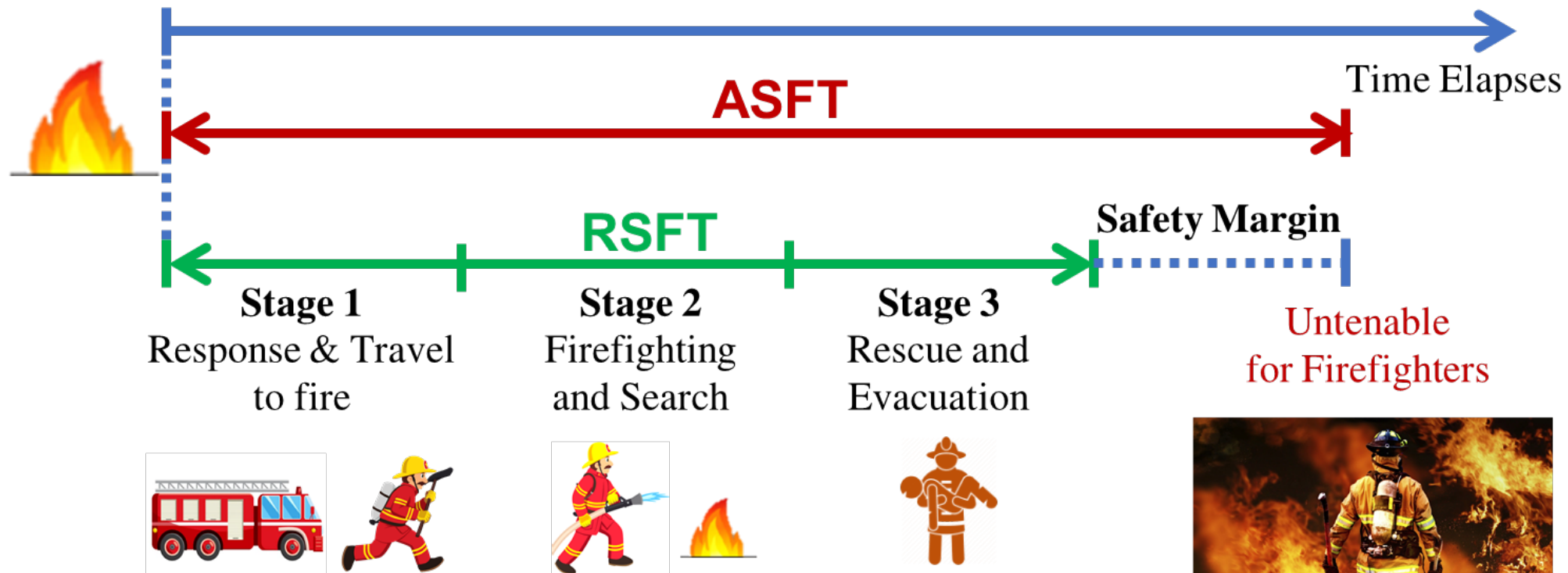
Aspects	Safe egress time (SET)	Safe firefighting time (SFT)
Tasks	Evacuation	Firefighting, search, rescue
Timeline	A couple of minutes	A few to dozens of minutes
Moving path	From inside to outside	From outside to inside, back-and-forth search, and then from inside to outside
Evacuation	By themselves	Post-firefighting with loads and injured occupants
Influence on fire	Little influence	Big influence on firefighting operations

Zhang, Y. X., et al. (2023). Design a safe firefighting time (SFT) for major fire disaster emergency response. International Journal of Disaster Risk Reduction, 88, 103606.

ASFT & RSFT

ASFT: Available safe firefighting time

RSFT: Required safe firefighting time

ASFT

RSFT

Time Elapses

Safety Margin

Stage 1
Response & Travel
to fire

Stage 2
Firefighting
and Search

Stage 3
Rescue and
Evacuation

Untenable
for Firefighters

ASFT: Available safe firefighting time

ASFT: time that elapses after the fire ignition until the presence of smoke, heat and poisonous gases create untenable conditions for firefighters with professional suits and facilities

$$\text{ASFT} = \min\{T_T, \ T_R, T_V, T_{CO}\}$$

ASFT Criteria	Evaluation indicator	Tolerable value (ASFT)	Reference value (ASET)
Principle	Temperature (°C)	< 80	< 60
	Thermal radiation (kW/m^2)	< 5	< 2.5
Secondary	Visibility (m)	Undetermined	>10
	CO	Not considered (with PPE) < 1000 (rescue task)	< 1000

RSFT: Required safe firefighting time

RSFT: time required for the firefighters to fulfill their tasks and withdraw to the safety zone with trapped occupants

$$\text{RSFT} = \sum_{i=1}^{n} f(M_t, \; D_j, \; C, \; B)$$

n = 3 and i = 1, 2, 3 refer to the firefighting tasks following the timeline.

- *i=1: when firefighters get noticed and arrive at the fire scene*

- *i=2: when firefighters execute their assigned firefighting and searching trapped people in the building*

- *i=3: when firefighters move out of the building and rescue trapped occupants to the outside;*

M_t : **the movement time** *for firefighters*

D_j : *firefighters' different* **duties** *and tasks;*

C : *the* **cooperation** *among groups such as communication and support between members;*

B : *the* **burden** *the firefighters carry during the rescue (firefighting facilities, injured people)*

The rules of safety in fire design

Current design rules:

Modified design rules:

$$ASET > RSET$$

$$\begin{cases} \textbf{ASET} > \textbf{RSET|F} \\ \textbf{ASFT} > \textbf{RSFT} \end{cases}$$

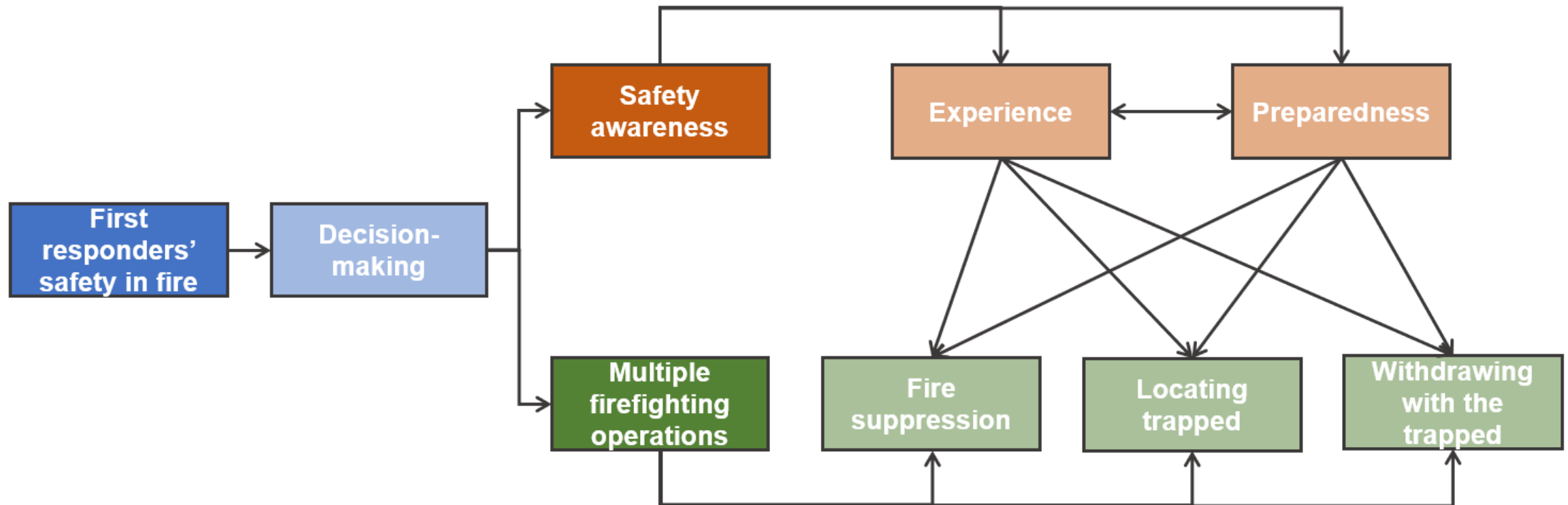- ASET should be larger than RSET

- With firefighting and rescue, RSET could be modified or shortened
- ASFT should be larger than RSFT so that the firefighters' safety could be guaranteed

Outline

1. Background

2. Previous work on firefighters: SFT

3. **Survey and results of firefighters**

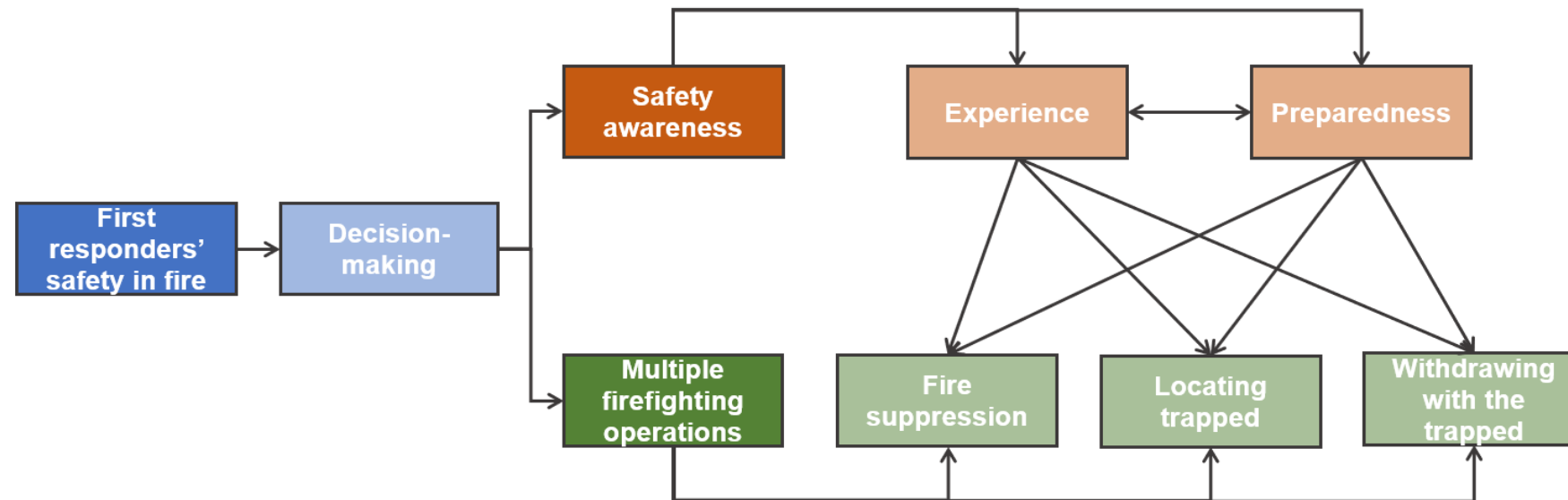4. Classification of firefighters based on decision-making preferences

Survey and results of firefighters

- How decision-making influences firefighter safety during operations
- Explore the impact of safety awareness on firefighters' adaptability
- Classify firefighters based on their decision-making preferences

Survey and results of firefighters

- Experience: Initial quality and characteristics such as age, years of service, education and injury history

- Preparedness to targeted fire scenes
  -four sections: the route to the fire, building layout, fire characteristics, and the status of trapped

Three firefighting operations
- fire suppression
- locating trapped individuals
- withdrawing with the trapped

External factors affecting fire suppression decision-making
- The distance to the fire source
- Fire intensity
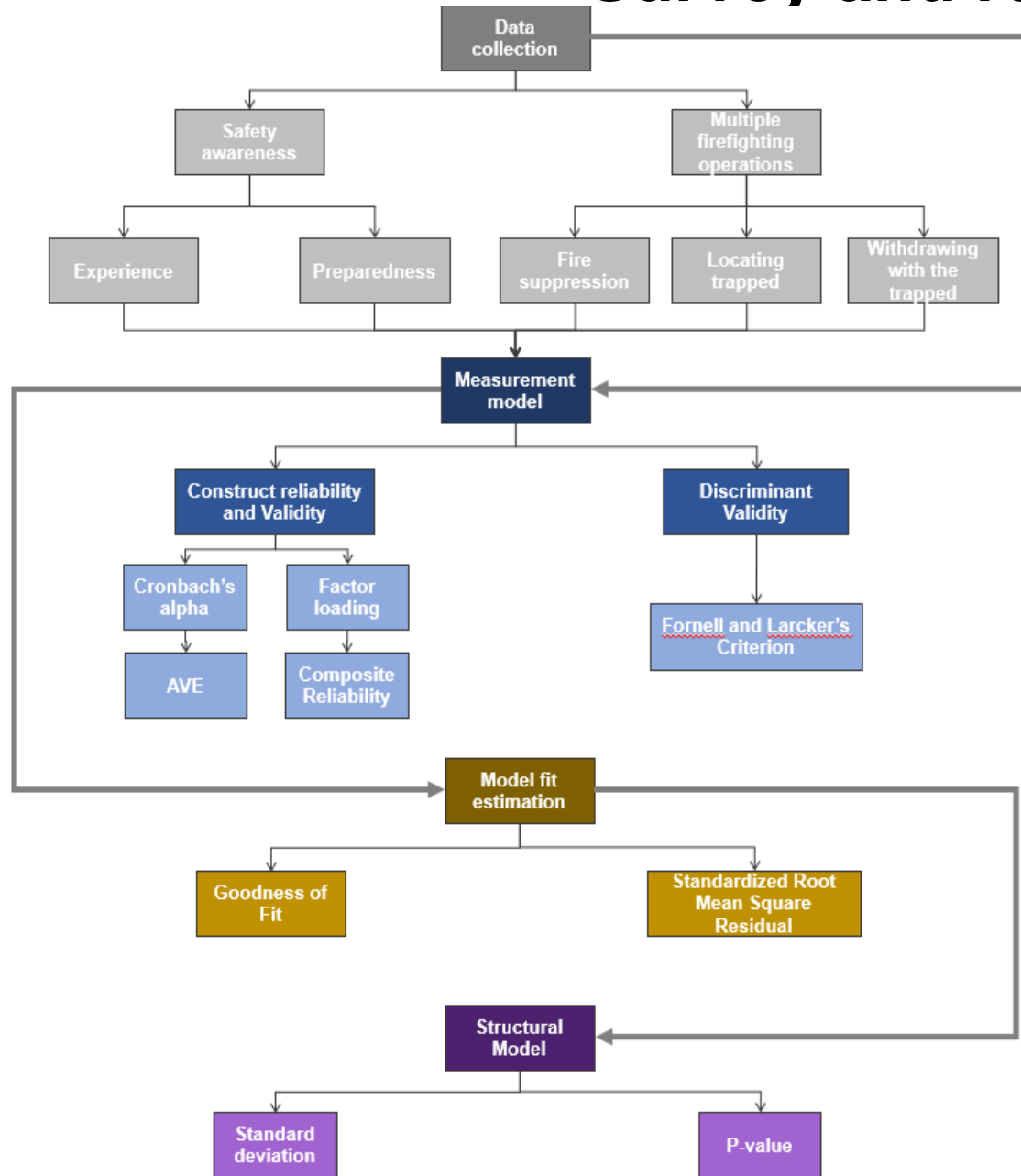- Smoke density
- Hazardous materials
- Team support

Survey and results of firefighters

Survey collected 141 firefighters in several urban fire brigades, and 129 valid

Category	Item	No.	Percentage
Gender	Male	129	100%
	Female	0	0%
Age	18-24	65	50.39%
	25-30	36	27.91%
	31-40	25	19.38%
	41-50	2	1.55%
	>51	1	0.78%
Years in firefighting	0-2	29	22.48%
	2-5	59	45.74%
	5-10	31	24.03%
	10-20	8	6.20%
	>20	3	2.32%
Education	Below high school	16	12.40%
	Diploma's degree	56	43.41%
	Bachelor's degree	45	34.88%
	Master or doctor	12	9.30%
Previous safety issues	No self-injury, nor witness of injuries of others	68	52.71%
	No self-injury, but witness of injuries of others	32	24.81%
	Minor self-injury	32	24.81%
	Major self-injury	7	5.43%

- **All firefighters are male.**
- **Around 70% of them have experience less than 5 years.**
- **Around 30% of them experienced injury.**

Survey and results of firefighters
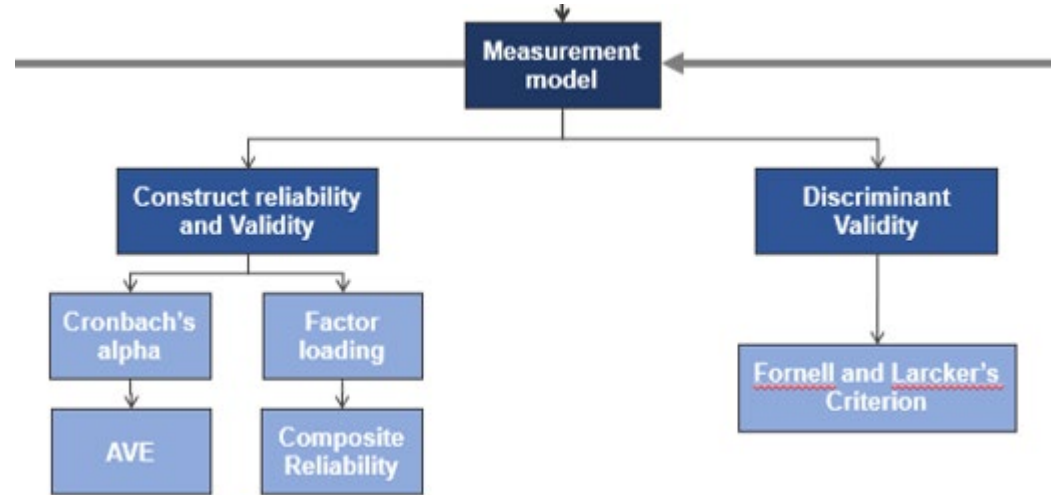

Step 1: Data collection of 129 firefighters

Step 2: Measurement models: to test if each question could represent the construct

Step 3: Model fit estimation: to determine the accuracy of the model

Step 4: Structure equation model: to analyze the relationship among each item

Survey and results of firefighters

Step 2: Measurement models: to test if each question could represent the construct

Constructs	Factor loading	Cronbach's Alpha	Composite reliability	AVE
SA-Experience	0.672-0.981	0.875	0.872	0.737
SA-Preparedness	0.851-0.919	0.932	0.933	0.779
FO-Fire suppression	0.542-0.880	0.935	0.963	0.764
FO-Locating trapped	0.602-0.839	0.963	0.967	0.806
FO-Withdrawing	0.519-0.858	0.967	0.935	0.675
Threshold	**0.5**	**0.5**	**0.7**	**0.5**

Survey and results of firefighters

Step 3: Model fit estimation: to determine the accuracy of the model

- **Goodness of fit (GoF)**

$$GoF = \sqrt{AVE_{avg} \times R^2_{avg}}$$

0.453> threshold: 0.36, showing large goodness of fit

- **Standardized root mean square residual (SRMR)**
  0.035 < threshold: 0.08, signifying a good model fit

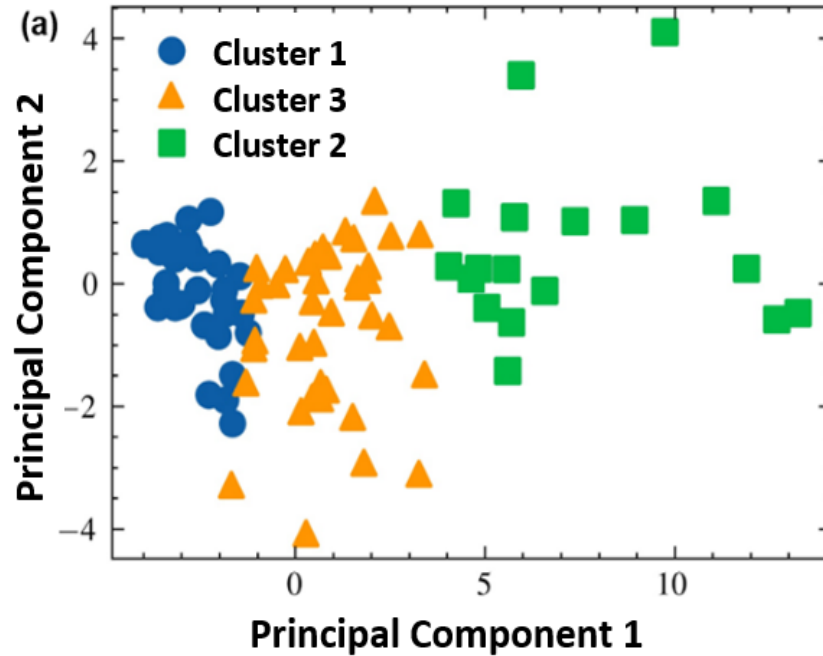**Step 4: Structure equation model: to analyze the relationship among each item**

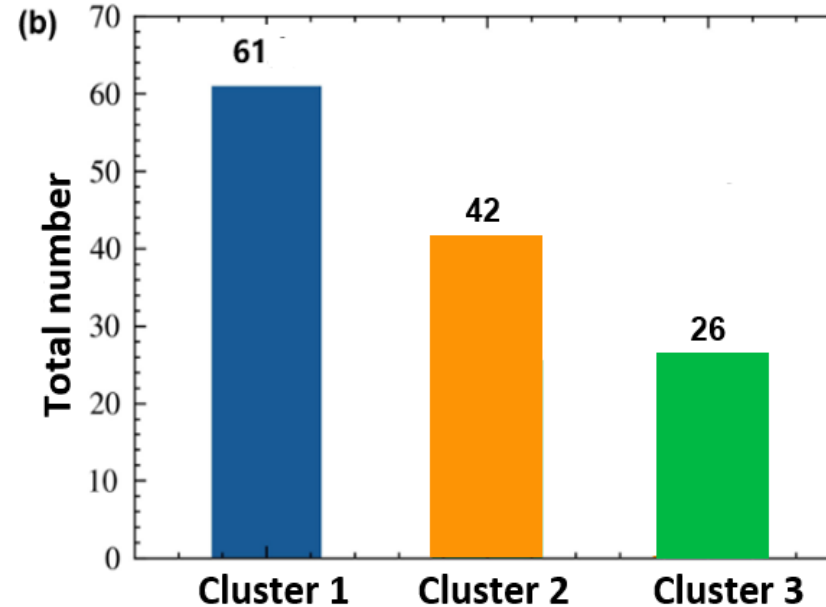| Hypotheses	Coefficient	STDEV	P-value	Influence
Experience →Fire suppression	0.271	0.076	0.000***	Positive
Experience →Locating trapped	0.081	0.056	0.062 #	Non-Positive
Experience →Withdrawing	0.136	0.062	0.003**	Medium Positive
Preparedness→Fire suppression	0.124	0.071	0.001**	Medium Positive
Preparedness→Locating trapped	0.242	0.058	0.000***	Positive
Preparedness→Withdrawing	0.145	0.064	0.000***	Positive

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4. **Classification of firefighters based on decision-making preferences**

Classification of firefighters based on decision-making preferences

Clustering analysis based on K-means
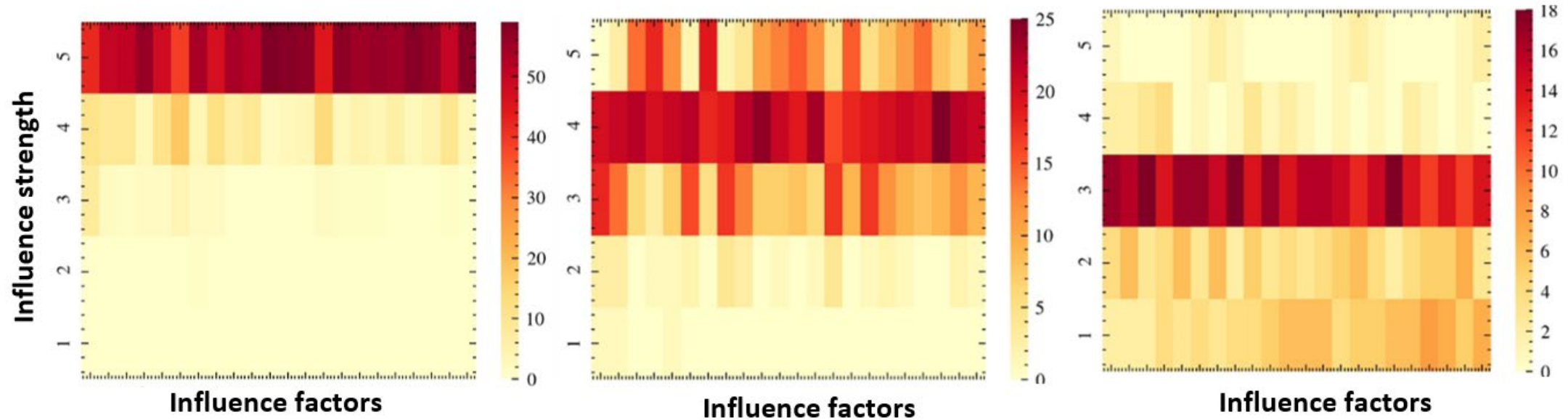

(a) Clustering analysis results;   (b) Clustering results statistics

Decision-making answers (22 dimensions) are reduced to two dimension.
129 firefighters are divided into three clusters based on their decision-making answers.

Classification of firefighters based on decision-making preferences

Clustering analysis based on K-means

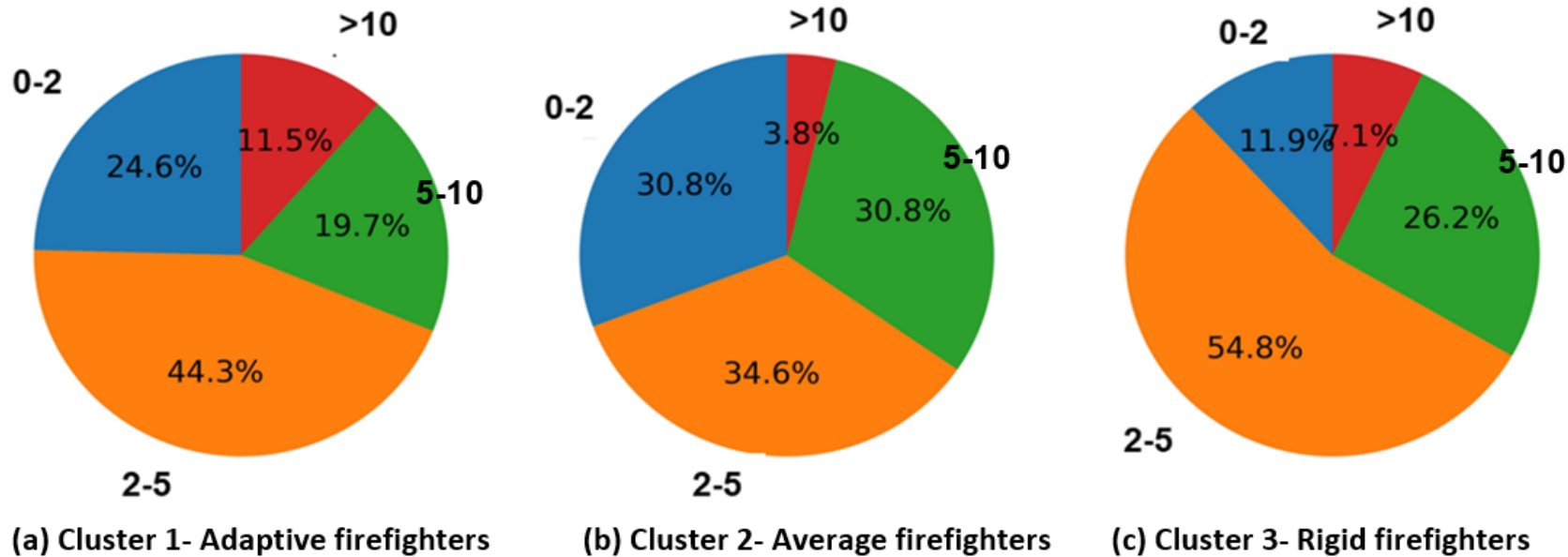(a) Cluster 1- Adaptive firefighters   (b) Cluster 2- Average firefighters   (c) Cluster 3- Rigid firefighters

The impact of fire-related factors on firefighters' decision-making among all three tasks

- Adaptive firefighters: **50%**, are influenced **highly** by external conditions
- Average firefighters: **30%**, are influenced **medium to highly** by external conditions.
- Rigid firefighters: **20%**, are influenced **medium or less** by external conditions.

Classification of firefighters based on decision-making preferences

Classification of firefighters and their experience

(a) Cluster 1- Adaptive firefighters   (b) Cluster 2- Average firefighters   (c) Cluster 3- Rigid firefighters
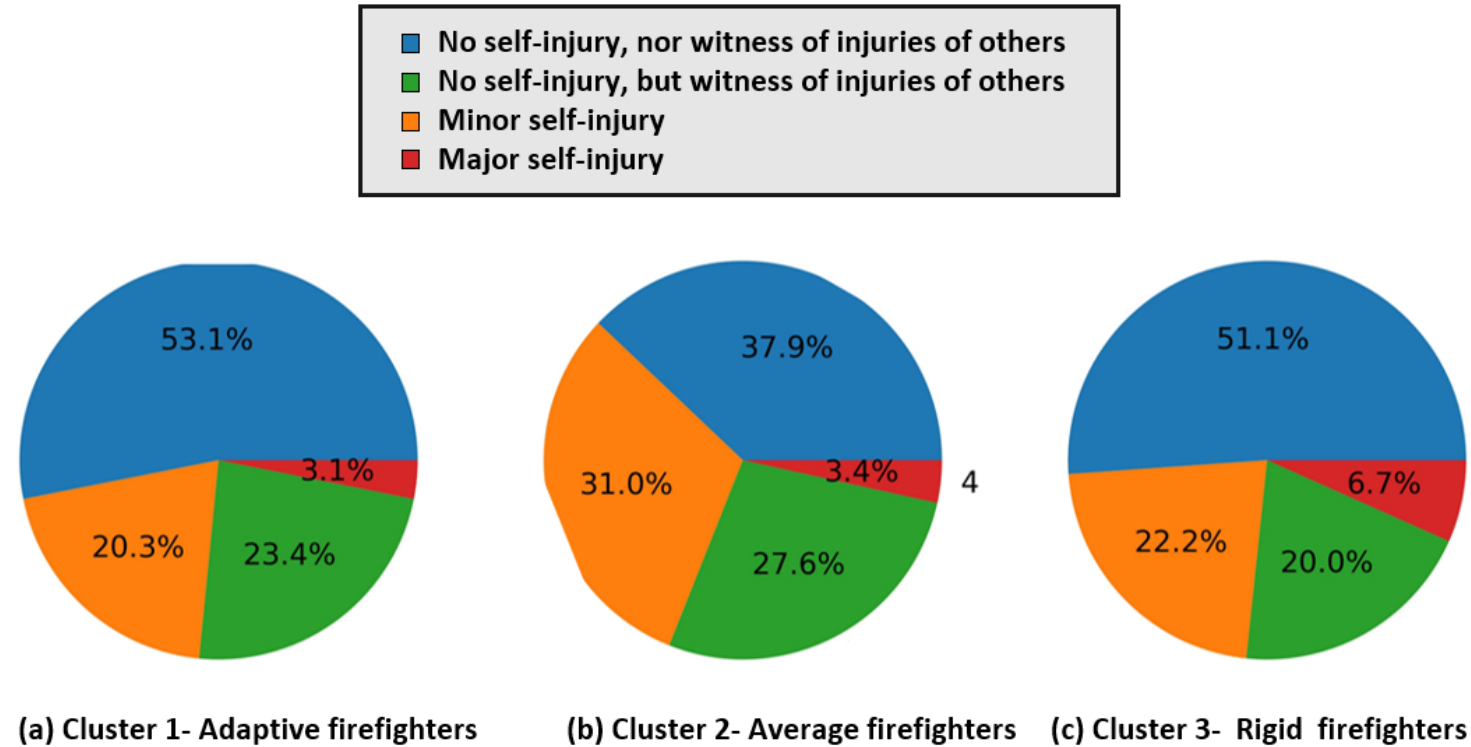
Clusters of firefighters and their years of service

- **11.5% of firefighters in the Adaptive Type (Cluster 1) have more than 10 years of experience, highest percentage.**
- **Rigid group has a higher proportion of less experienced firefighters, having just 2-5 years of service.**
- **New recruits, with less than 2 years of service, rely highly on external factors.**

Classification of firefighters based on decision-making preferences

Classification of firefighters and their experience

Legend:
- ■ No self-injury, nor witness of injuries of others (blue)
- ■ No self-injury, but witness of injuries of others (green)
- ■ Minor self-injury (orange)
- ■ Major self-injury (red)

(a) Cluster 1- Adaptive firefighters: 53.1%, 3.1%, 23.4%, 20.3%

(b) Cluster 2- Average firefighters: 37.9%, 3.4%, 4, 27.6%, 31.0%

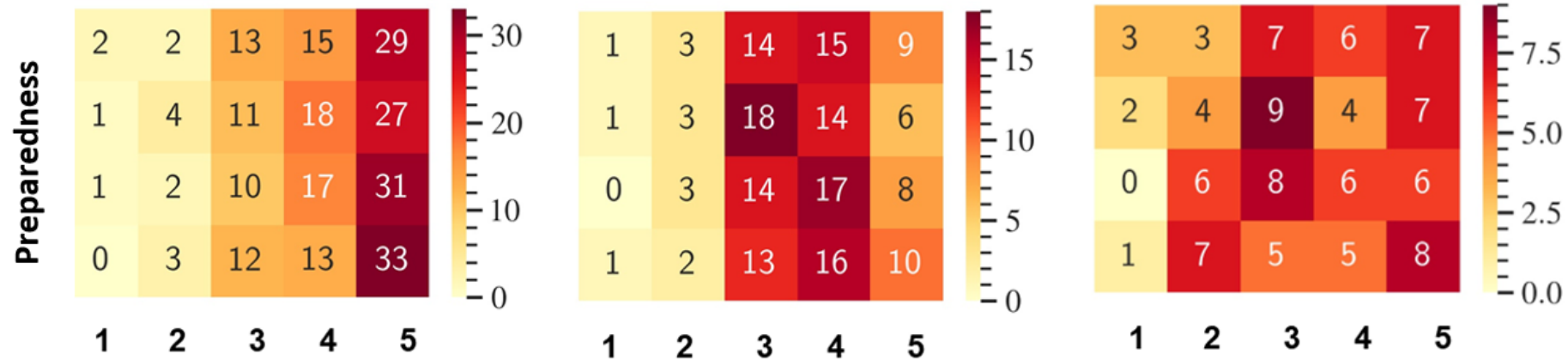(c) Cluster 3- Rigid firefighters: 51.1%, 6.7%, 20.0%, 22.2%

Clusters of firefighters and their pervious safety issues

- **Rigid group** have a higher proportion of injuries than other two clusters.
- **Adaptive group** are the safest with the least injuries

Classification of firefighters based on decision-making preferences

Classification of firefighters and their preparedness

(a) Cluster 1- Adaptive firefighters   (b) Cluster 2- Average firefighters   (c) Cluster 3- Rigid firefighters

Clusters of firefighters and their preparedness

- Adaptive firefighters are generally very familiar with all four types of fire-related information.
- Average firefighters display a range with fire information, mid-familiar to very familiar.
- Rigid firefighters fall within the board range of "unfamiliar" to "very familiar".

Conclusions

- **129 firefighters' response to decision-making factors are surveyed.**

- **Experience is a double-edged sword.**

- **Preparedness showed strong positive effects across all tasks.**

- **Firefighters are divided into three clusters: adaptive, average and rigid**

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