Vulnerability Analysis of High-speed Railway System under Typhoon Disasters in China

关键基础设施与城市韧性
Critical Infrastructure & City Resilience

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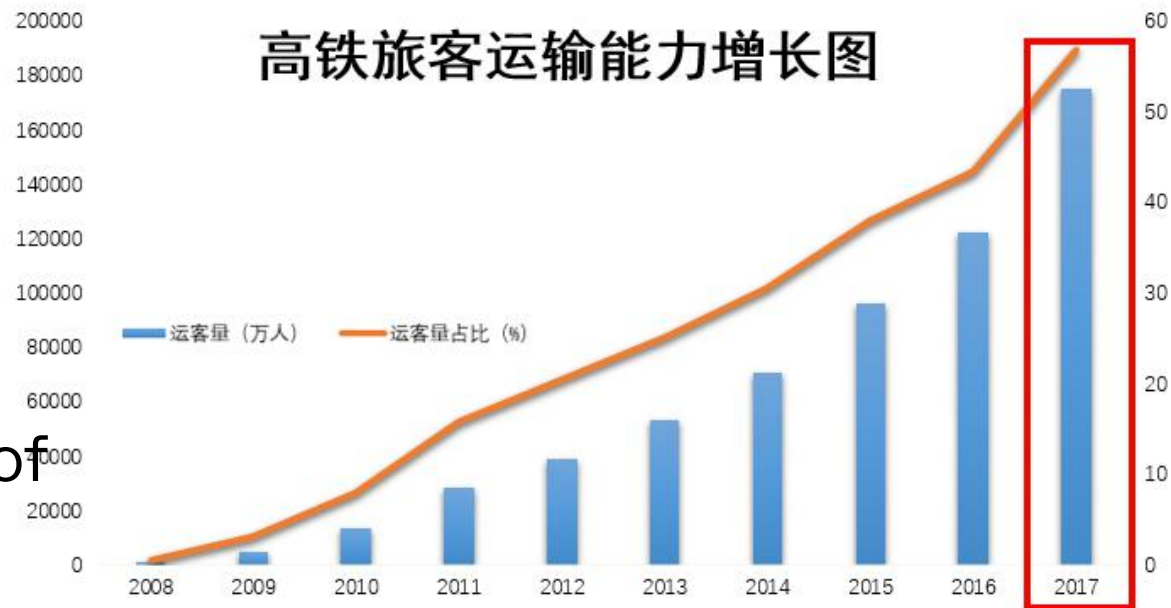School of Artificial Intelligence and Automation
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OUTLINE

1. Background

2. Modeling

3. Case Study

4. Conclusion

1.   Background

◆ The operating track length exceeds **20,000 kilometers**, accounting for more than 60% of the world's

◆ An average of **4.7 million passengers** are sent every day

高铁旅客运输能力增长图

运客量（万人）　运客量占比（%）

➤ 高铁运客量**占比逐年增加**
➤ 2017年旅客发送量**17.5亿人次，占56.8%**

普速铁路 13.3亿 43.2%
高速铁路 17.5亿 56.8%

2017年高铁旅客发送量占比

四横四纵

2020年 高速铁路网

八横八纵

□ There are 20 typhoons affecting China's coast every year, of which 8 landfall

□ HSR in coastal areas are densely distributed

03-April-2018 Typhoon Lark

Landing in Shanghai, Jinshan. Level 9

➤ More than 120 high-speed trains have been suspended
➤ The Yangtze River Delta region is affected

16-Sep-2018 Typhoon Mangkhut

Landed in Taishan, Guangdong. Level 14

➤ More than 1,500 high-speed trains have been suspended, accounting for more than 15% of the total operation
➤ 9/16, Guangdong and Hainan high-speed trains were completely suspended
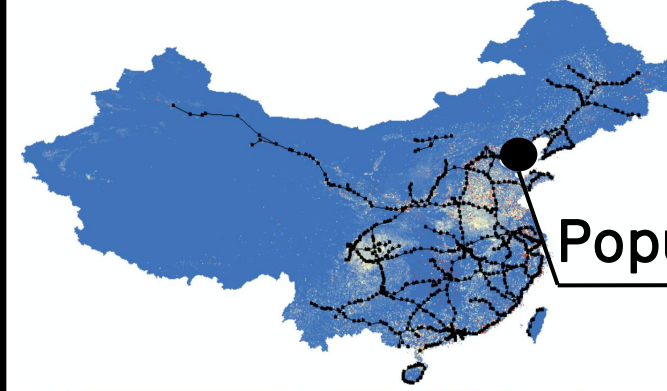
1.Background 1.4 What is HSR System

Data Demands

HSR Map

Operation Timetable

Population Distribution

Typhoon historical data

G Type

D Type

C Type

HSR System = High-speed Railway + High-speed Trains（G D C）

2.Modeling

Physical layer

Nodes：Train Stations
Edges： Railway

Service layer

Nodes：Train Stations
Edges：If two points can be reached directly by high–speed train, it is considered that there is an edge between the two points
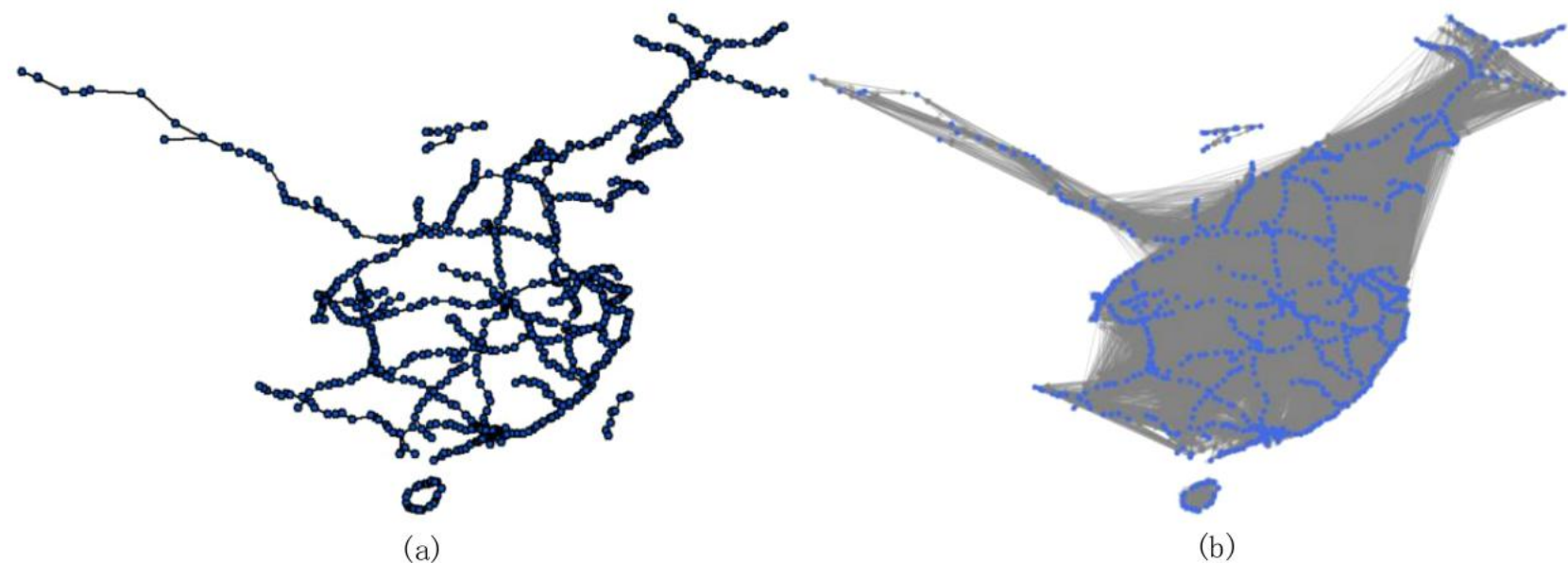

(a)

(b)

图 3-1 中国高铁系统网络化建模 （a）高铁系统物理层网络化建模

（b）高铁系统服务层网络化建模（只包括中国大陆地区）

高铁系统网络基础特性表

	N	M	$\bar{k}$	$\bar{l}(km)$	$\bar{d}(km)$
物理层网络G_p	899	926	2.1	31.3	1253.7
服务层网络G_s	899	53618	119.3	1094.3	3032.8

How to determine the failure zone

Physical layer → ← **Service layer**
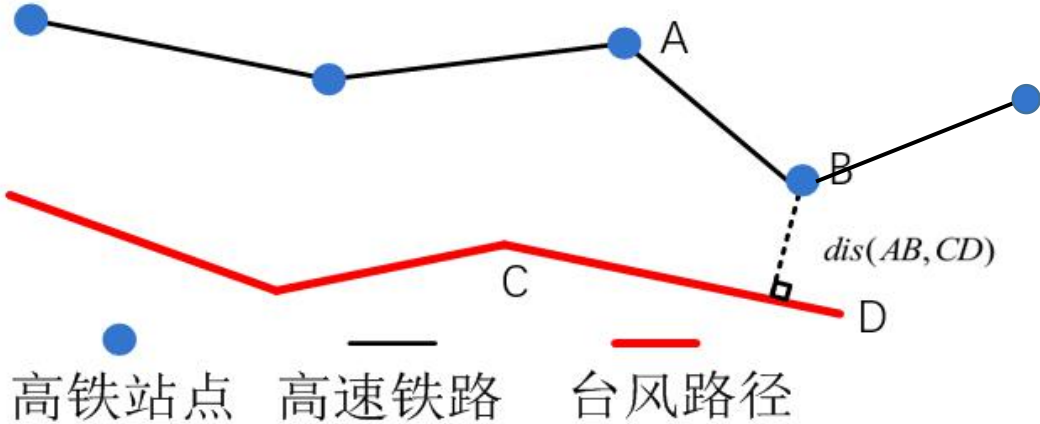
The risk of trains running on HSR closest to the typhoon's path is too high, causing the train to stop running

Fragibillity

$dis(AB,CD)$

高铁站点　　高速铁路　　台风路径

day	train_id	min_dis(km)	wind_speed(m/s)	label
16	d5601	1061.37991	45.65	0
16	g1670	514.0312249	45.65	0
16	d7345	252.8461339	45.65	1
16	g1747	145.459077	45.65	1
17	d7530	362.6745324	22.39	0
17	d4116	263.7915314	22.39	0
17	d932	124.6121884	22.39	1

列车线路与台风路径的距离　　台风风力等级　列车运行状态

day	train_id	min_dis(km)	wind_speed(m/s)	label
16	d5601	1061.37991	45.65	0
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17	d4116	263.7915314	22.39	0
17	d932	124.6121884	22.39	1

Equation for wind speed decay

$$v(x,y;t) = v_m \left\{ \left(\frac{R_m}{r}\right)^b e^{\left[1-\left(\frac{R_m}{r}\right)^b\right]} \right\}^a$$

Holland et al.(2010)

Logistic Regression Mdel

$$h_\theta(x) = g(\theta^T x) = \frac{1}{1+e^{-\theta^T x}}$$

$$P(y\,|\,x;\theta) = (h_\theta(x))^y (1-h_\theta(x))^{(1-y)}$$

AUC > 0.9

易损性

近地风速（m/s）
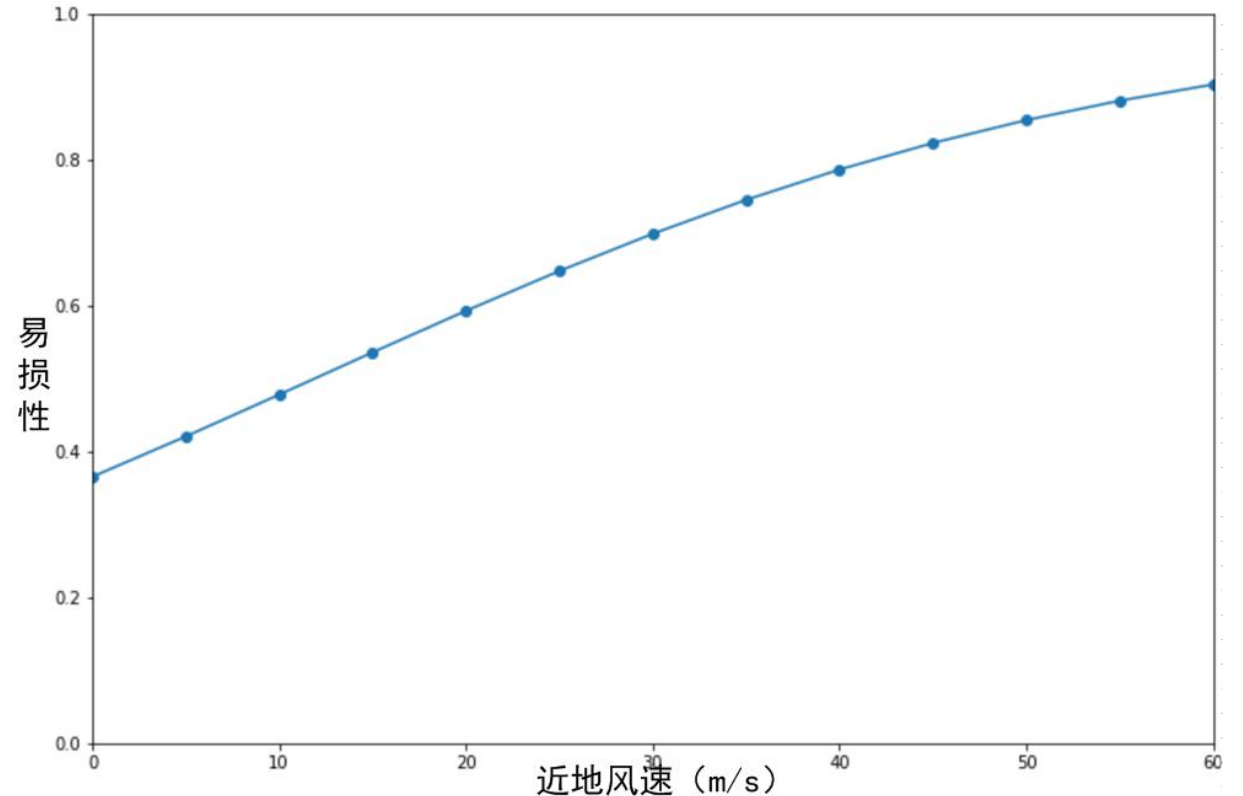
Fragibility of HSR's Componets

1.Accessibility under normal conditions f^n_{acc}
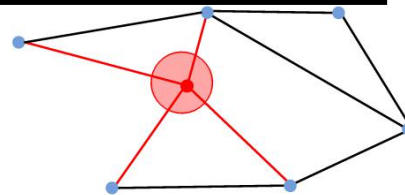
2.Simulation of disaster scenarios d

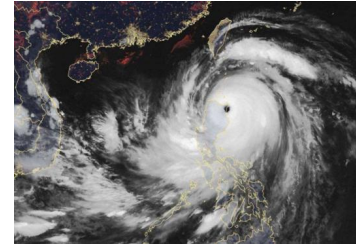3.Accessibility after disaster f^d_{acc}

4.Evaluation of Vulnerability

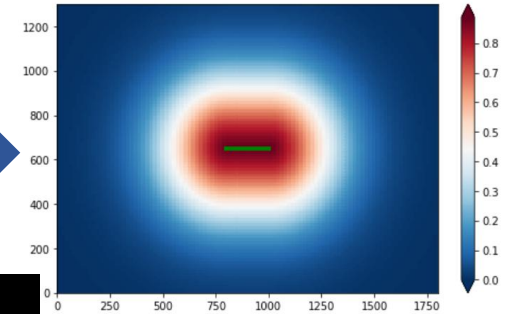$$vul(d) = \frac{f^n_{acc} - f^d_{acc}}{f^n_{acc}}$$

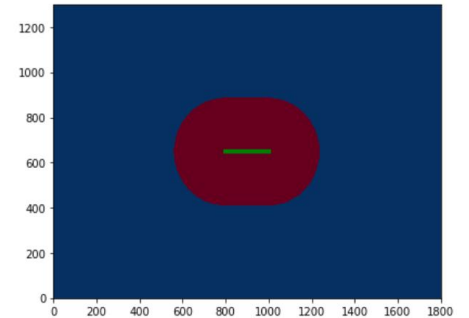Indicator is travel time

Nelson et al.(2018)

Lacal Attack

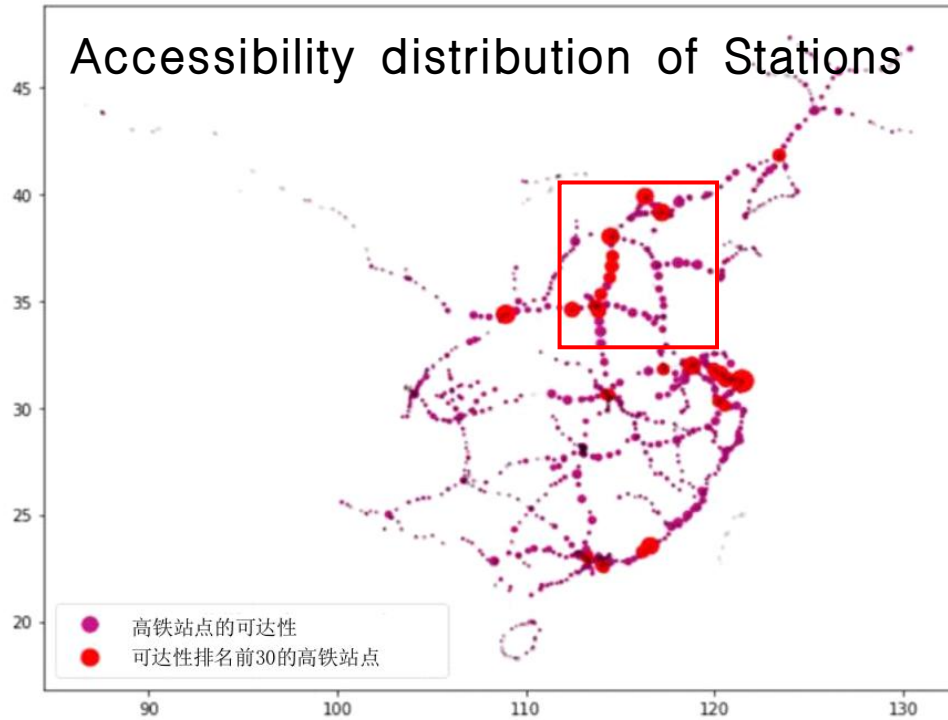Typhoon Scenario

Fragibility Distribution

Identify Damaged Areas

3. Case Study

Accessibility distribution of Stations
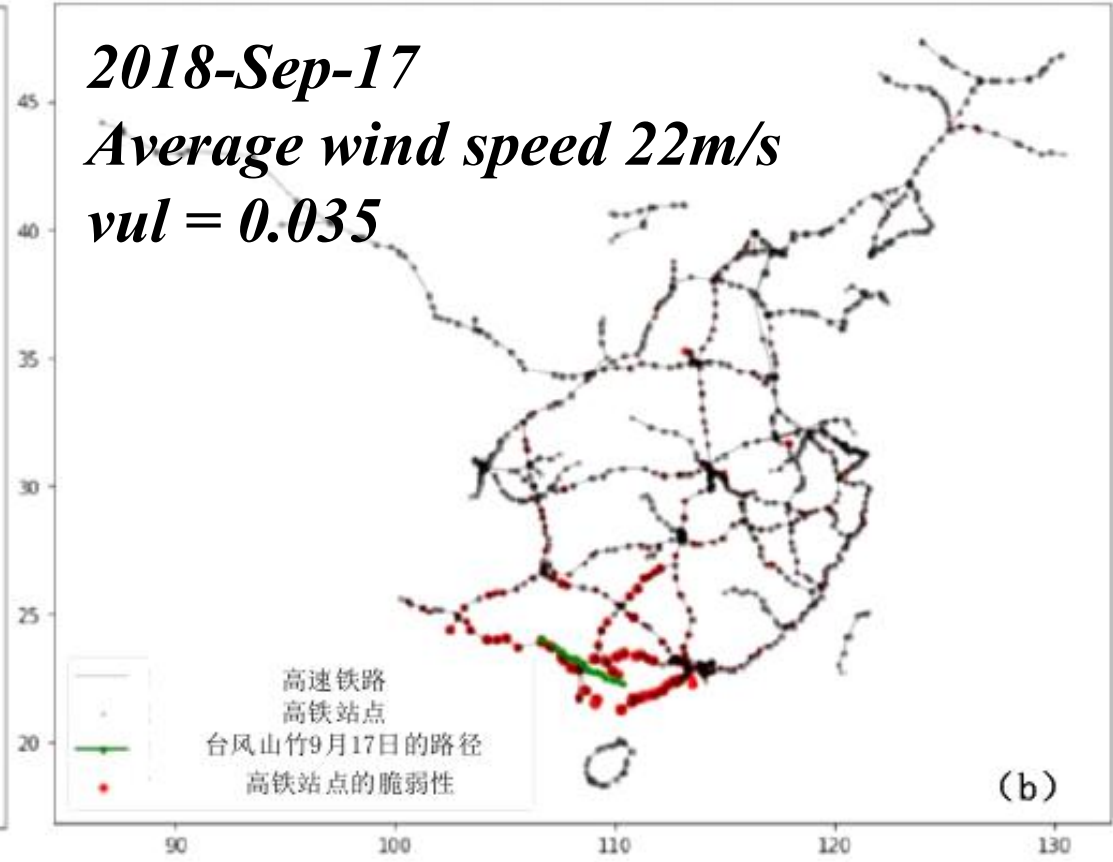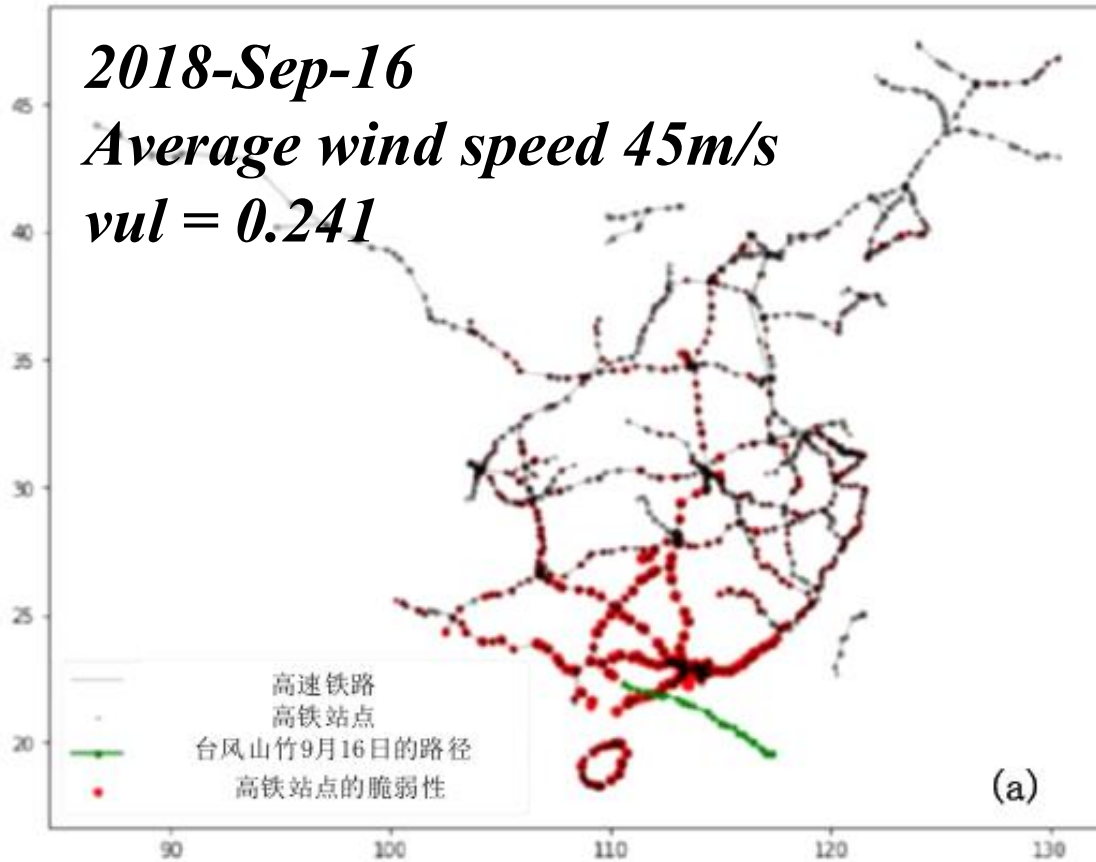
Per Capita Accessibility of Stations

(b)

- HSR stations with high accessibility are mainly distributed in the Beijing–Tianjin–Hebei, Yangtze River Delta and Pearl River Delta economic circles
- The Beijing–Tianjin wing area has also driven the development of the surrounding high–speed rail city circle (Zhengzhou↔Shijiazhuang↔Beijing–Tianjin–Hebei line))
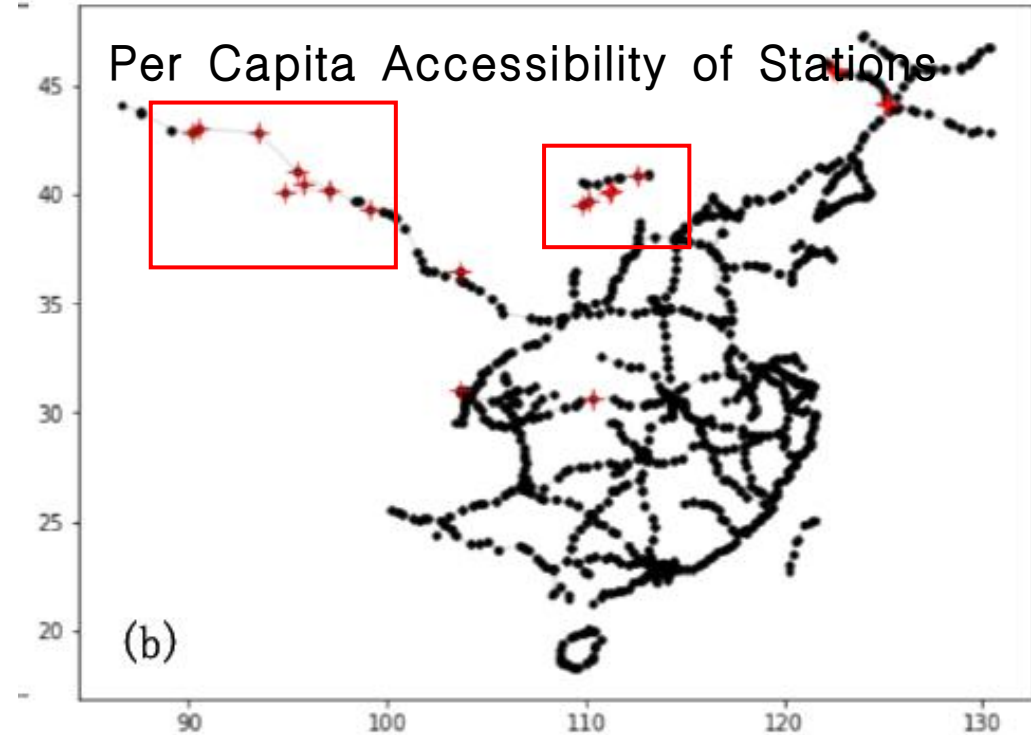
- Urumqi↔Lanzhou line (the location is relatively remote),
- ✓ Direct high–speed trains running at increased speed
- Ordos↔Hohhot line (in isolation)
- ✓ Connected to the main network (the 13th Five–Year Development Plan)

(a) 2018-Sep-16, Average wind speed 45m/s, vul = 0.241
(b) 2018-Sep-17, Average wind speed 22m/s, vul = 0.035

➤ 9/16, Mangkhut passed through the densely populated Pearl River Delta region with high wind speed of 45m/s

➤ 9/17, the wind power level of mangosteen was halved. Mangosteen mainly passed through Nanning area, and the affected area was 1/8 of that on 9/16.

➤ Most of the affected areas during 9/16 were back to normal on 9/17

Historical data of Typhoon（1949~2019）

Fragibility of Satations

Vulnerability distribution
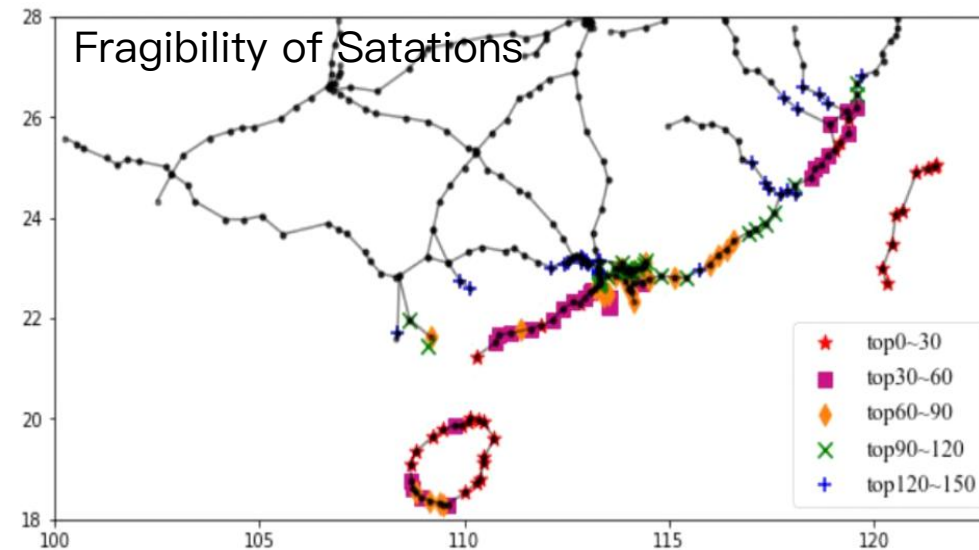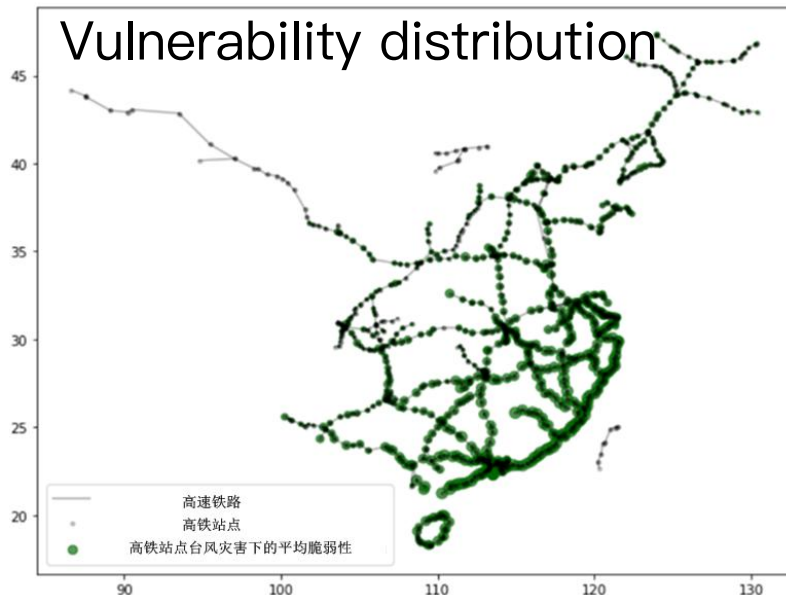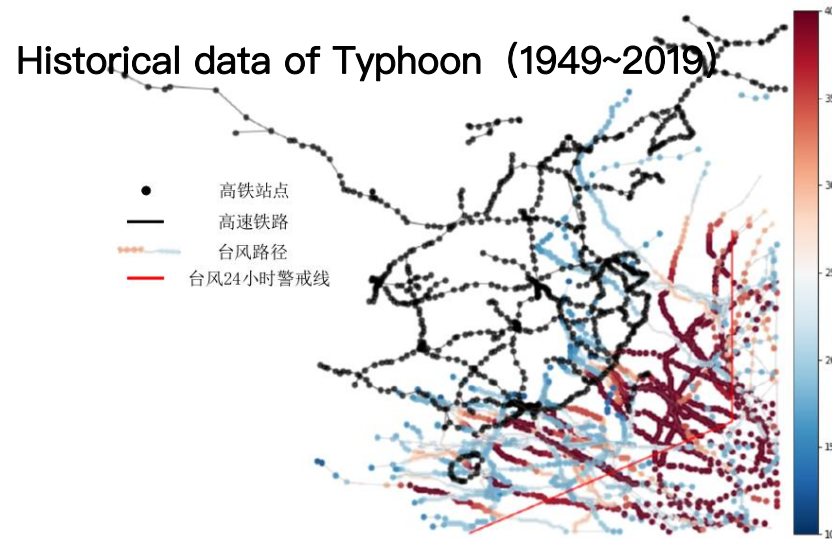
➢ Along the Zhanjiang West–Guangzhou route, and along the Fujian–Xiamen route, outside the typhoon buffer zone

➢ The Pearl River Delta region and the Yangtze River Delta region need to build backup tracks and routes to reduce the impact of typhoons on economic activities

r=260km

9月16日台风山竹路径
9月17日台风山竹路径
9月16日台风山竹等效
局域攻击情形
9月17日台风山竹等效
局域攻击情形

r=541km
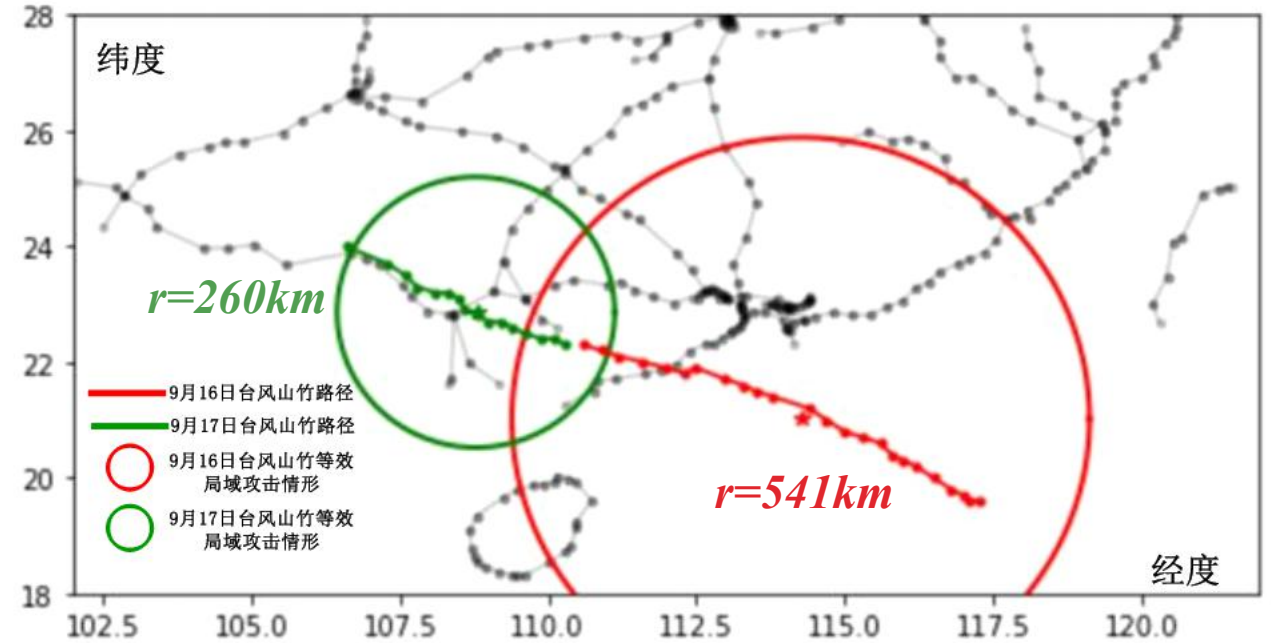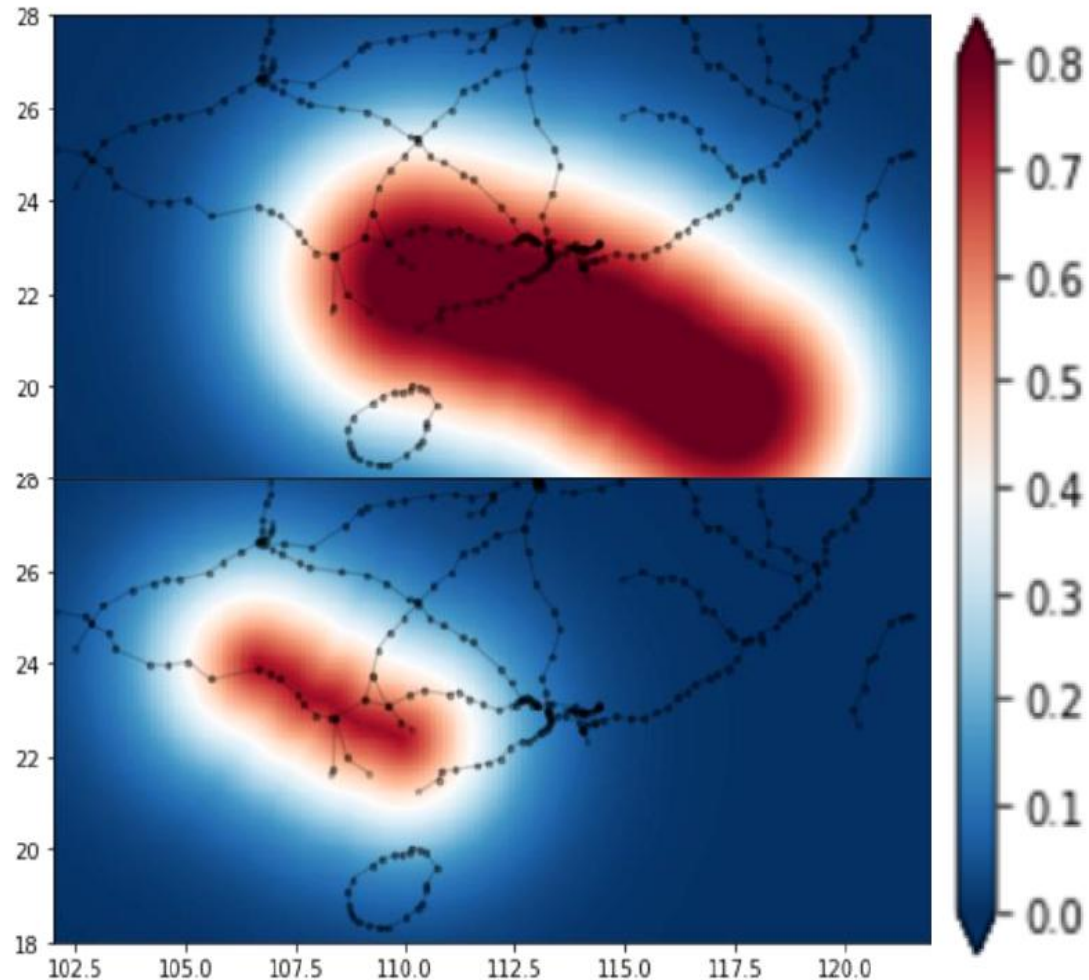
> Quantifying typhoon disaster events with local attack events
> Vulnerable areas can be viewed as localized attack events moving along the typhoon's path

4. Conclusion

Method
- ➢ Modeling fragibility of HSR's components under typhoon scenarios
- ➢ Framwork of vulnerability analysis
- ➢ Explore relationships between local attack and typhoon disasters

Conclusion
- ✓ Accessibility：Advice for HSR's rails planning
- ✓ Vulnerability：reference for reinforcement measures to prevent typhoons

Future
- ❖ More outage data under typhoon scenarios
- ❖ Typhoon generation model

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Thanks