How Extreme Weather Influences a Taxi Market: Spatio-temporal Analysis for Transport Policy Insights

R. C. P. Wong
Department of Civil Engineering
The University of Hong Kong, Hong Kong
Email: cpwryan@hku.hk

P. L. Mak
Department of Civil Engineering
The University of Hong Kong, Hong Kong
Email: patrickmak.66@gmail.com

W. Y. Szeto
Department of Civil Engineering
The University of Hong Kong, Hong Kong
Email: ceszeto@hku.hk

W. H. Yang
Department of Civil Engineering
The University of Hong Kong, Hong Kong
Email: yangwenh@connect.hku.hk

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ABSTRACT

Extreme weather conditions, strong gust, and torrential rainfall threaten the safety of the general public and restrict people's travel options. Most of the transportation modes are suspended due to safety reasons. Taxis are one of the only few available non-private transport modes to provide services to those who have urgent and unavoidable travel needs. This study uses global positioning system data collected from 460 Hong Kong urban taxis during nine ordinary and one tropical cyclone periods aiming to find out and explain the differences in terms of the percentage of taxis not in operation, the number of served passenger-trips, average time spent for vacant taxi drivers finding a customer, and the percentage of taxi drivers in cross-district customer-search throughout the same 48-hour duration. The finding shows an inadequate level of taxi supply and a high passenger demand during the tropical cyclone-affected period. Up to 80% of taxis were not in operation to serve the urgent and necessary trips. The average customer-search time for taxi drivers, which is anticipated inversely proportional to the demand for taxi rides, was very short (about five minutes). Policy measures are discussed and recommended to the government to improve the taxi services during extreme weather conditions.

Keywords: Extreme Weather, Tropical Cyclone, Taxi Customer-search, Spatio-temporal Analysis, Global Positioning System Data

INTRODUCTION

Extreme Weather

Tropical cyclones, heavy rain, heavy snow, thunderstorms, gale, and fog have been classified by the World Meteorological Organization as the six types of global extreme weather conditions (*1*). In the East-Asia, the two most common extreme weather conditions are tropical cyclones (also known as typhoons) and heavy rain. They usually come together and attack the coastal cities during the summer months (i.e., July to October) one to three times per year (*2*). In the past twenty years, numerous cases demonstrated the relationship between the frequency, cause, intensity, track, forecasting, and destructiveness of tropical cyclones and a warming climate. It is suggested that global warming had a positive effect on the increasing activity of tropical cyclones in the region (*3*, *4*). Many other studies (*5*–*8*) found similar results based on observations or model simulations. The meteorological circle agreed that the percentage of severe tropical cyclones (*2*), the intensity of each tropical cyclone (*9*), and the precipitation level (*10*) are in an increasing trend. Therefore, the impact of tropical cyclones and their associated heavy rain to the coastal cities in East-Asia will become more and more severe.

Every year, tropical cyclones attacked Japan, Mainland China, Taiwan, the Philippines, Vietnam, and Hong Kong, which caused landfall, flooding, and other destructions, and people were killed or seriously injured. Over the years between 1961 and 2010, the average number of tropical cyclones that reached Hong Kong was 15.6 per annum, and 6.0 of which caused issuing tropical cyclone warning signals (*11*). Hong Kong Observatory issues warning signals under the circumstances where the track of a tropical cyclone enters an 800-kilometer radius. The current system operates with eight different warning signals accordingly to the level of severity, as shown in **Figure 1**, increasing from Warning Signals Nos. 1, 3, 8 (which can be further classified as 8-Northeast, 8-Northwest, 8-Southeast, and 8-Southwest, based on the wind directions), 9 to 10 (*12*). A tropical cyclone often carries strong wind and induces peripheral precipitation, which certainly causes disruption to traffic and limits people's travel options.

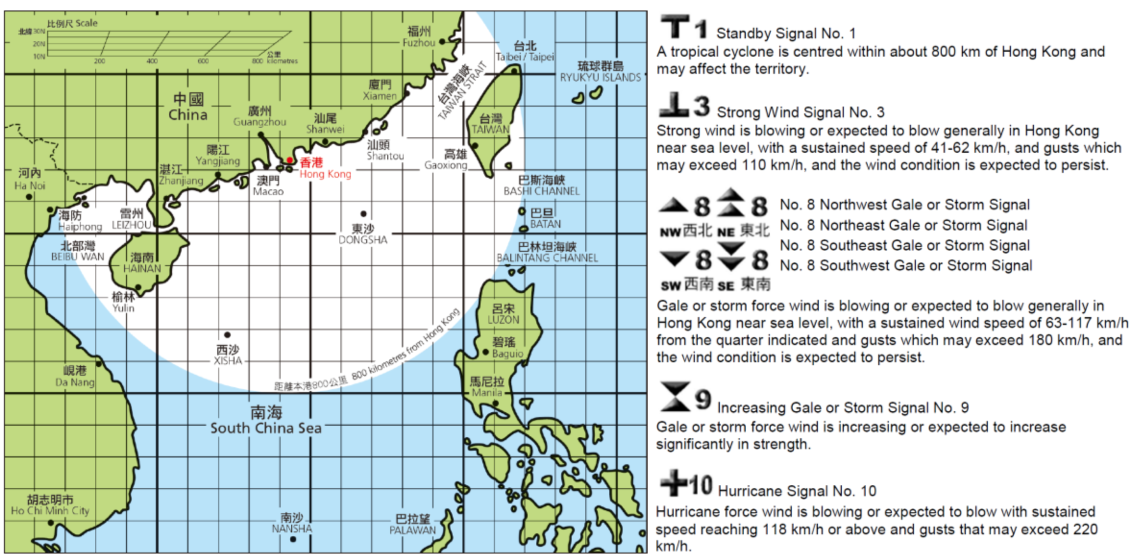

Figure 1 Tropical cyclone warning signals

Public Transport Provision in the Presence of Extreme Weather

When a tropical cyclone approaches Hong Kong, Hong Kong Observatory notifies the general public approximately two hours before the possible issuance of Warning Signal No. 8 (*13*). Employers are advised to release their employees from duty in a staggered manner, except when prior arrangements were made (*14*). Education Bureau announces the closure of all schools, and schools should arrange students to return home under safe conditions (*15*). Yet, this inevitably creates high travel demand, the over-concentration of passenger flow, and an excessive load to public transport facilities. Long queues at bus stops and railway stations are common sights during such an event. The public transport services may be suspended or become limited at short notice due to the progression of the storm. Therefore, demand within the 2-hour advance notice period may not be fully absorbed. After the event, workers are also required to return to their duties within two hours after the cancellation of Warning Signal No. 8 if the time of cancellation is three hours or more before the end of normal working hours (*14*). All school activities are resumed if the No. 3 Signal has been issued before 5:30 am for AM and whole-day schools, and before 10:30 am for PM schools (*15*). Although public transport services are resumed after the cancellation of No. 8 Signal, the massive number of people returning to work and school adds a high concentration of demand to the transportation system within a short period. This chaotic traffic condition sometimes attracted criticism for either being too cautious or not being cautious enough when the weather forecast was not accurate.

Previous studies have evaluated the impact of weather conditions on transit ridership in different seasons and modeled the ridership under different meteorological variables, including the effect of precipitation, temperature, wind, snow, air humidity, and air pressure, using data from global positioning systems (GPS) and Smartcards (*16*–*19*). It is understandable and a common practice that most public transport modes are suspended under extreme weather conditions, and this is inevitably becoming more so if the intensity of extreme weather is increasing. When all over-ground public transport services are suspended, taxis have become the only non-private transport mode that is accessible to the general public. Although limited railway services at the least affected sections may still be offered, all feeder services may have suspended their operation. Taxis are the only means of transport for passengers traveling between railway stations and their abode. Taxis are also crucial for residents of remote and low-lying areas that are prone to landfall and flooding, where an emergency evacuation is needed. Moreover, for those who could not be released from duties during the advance notice period may still need to travel back to home safely when storm progresses and weather condition deteriorates, taxis are then their only option.

Empirical evidence obtained from New York City shows that the presence of extreme weather substantially increased the door-to-door transportation service demand (*20*). A household behavioral survey conducted for the U.S. Army Corps of Engineers study also indicates that over 6% of the reported evacuation trips made by taxis during the attack of Hurricane Irene in 2011. Taxis played a supportive role in the public transportation systems in an emergency when public transit services were suspended. Bian et al. (*21*) further investigated the spatio-temporal variations of taxi ridership in the period leading up to hurricane landfall, and Zhu et al. (*22*) studied the recovery patterns of roadways during the post-hurricane period. However, these studies focused on either before or after the extreme weather condition, which did not capture the numbers of taxi drivers who stopped working, kept working, and resumed working before, during, and after the event. A comprehensive study to investigate the influences of extreme weather on a taxi market in the entire affected period is required to monitor the hourly variation of taxi supply and introduce effective taxi policy measures for encouraging taxi drivers to serve evacuation trips or trips made during the extreme weather condition.

In Hong Kong, Labour Department recommends taxis as a preferred mode of safe transport for employers to provide to their employees, who are required to travel between their workplace and home during the tropical cyclone-affected period (*14*). However, there is a paradoxical phenomenon that the government encourages commuters to use taxis but the ambiguous insurance clauses and hefty additional premium stop taxi drivers from operating during an extreme weather condition. The unbalance between demand and supply, as well as the gap between service expectation and service delivered are both worsened. Moreover, when the overall passenger demand is low, taxi drivers tend to search for customers in urban areas on normal days (*23*). Likely, even less taxi supply can be anticipated in remote rural areas where the local households depend on taxis as a means of evacuation. A spatial analysis of passenger demand to assist Transport Department or taxi operators in dispatching taxis to the districts in need during extreme weather conditions is necessary.

Objectives of This Research

To understand the demand-supply of taxi services and reveal the changes in taxi availability and ridership, and examine customer-search decisions of vacant taxi drivers caused by a tropical cyclone to draw taxi policy insights, this study selects tropical cyclone Koppu that stroke Hong Kong from 13 to 15 September 2009 as a case study. Koppu was near Hong Kong for approximately 48 hours. Its most powerful phase covered a period from the afternoon peak to mid-day on the following day, which allowed us to capture the proportion of taxis not in operation, served passenger-trips per taxi, average customer-search time, and cross-district customer-search decisions at the time of people releasing from work and school before the attack of the tropical cyclone, and returning to work and school afterward based on the GPS data of 460 urban taxis. The contributions of this study are 1) as one of the pioneer studies demonstrating the significant difference in taxi availability and ridership, and customer-search decisions of vacant taxi drivers in normal days and during a tropical cyclone-affected period; 2) identifying the spatio-temporal passenger demand to assist Transport Department and taxi operators in dispatching taxis during extreme weather conditions to serve evacuation trips or trips made during such conditions; and 3) exploring the areas of possible policy changes and suggesting transport policy measures for improving the performance of a taxi market.

DATA

The GPS data of urban taxis has been widely used in previous research to study the route choice behavior of drivers and the taxi ridership (*23–25*). In this study, the GPS data was collected from 460 urban taxis that recorded the drivers' daily activities, including their locations, spot travel speed, engine status, and occupational status in every 30 seconds. The sample of 460 taxis represents approximately 3% of the entire taxi population, and adequately represents the overall travel behavior of the vacant taxi drivers and passenger demand in an extreme weather condition.

This study selected tropical cyclone Koppu as a case study, which passed through the western North Pacific on 12 September. It started approaching Hong Kong on 13 September and the Standby Signal No. 1 was hoisted at 8:35 pm. The No. 3 Signal was subsequently issued at 11:15 am on the following day while Koppu kept moving towards Hong Kong in the afternoon with increasing strong wind from the northeast. As Koppu continued to move closer to Hong Kong, Hong Kong Observatory issued the No. 8 Northeast Warning Signal at 5:55 pm (typical evening peak hours), and the No. 8 Southeast Warning Signal at 12:35 am next day when the wind gradually changed its direction to the southeast at night. Koppu was at its closest to Hong Kong at around 1 am with the highest recorded wind speed during this tropical cyclone-affected period. Thereafter, the typhoon gradually subsided in the morning. The No. 8 Warning Signal was superseded by the No. 3 Signal at 10:15 am (typical morning peak hours), and further downgraded to the No. 1 Signal at 1:35 pm. Finally, all typhoon signals were canceled at 3:40 pm (*26*).

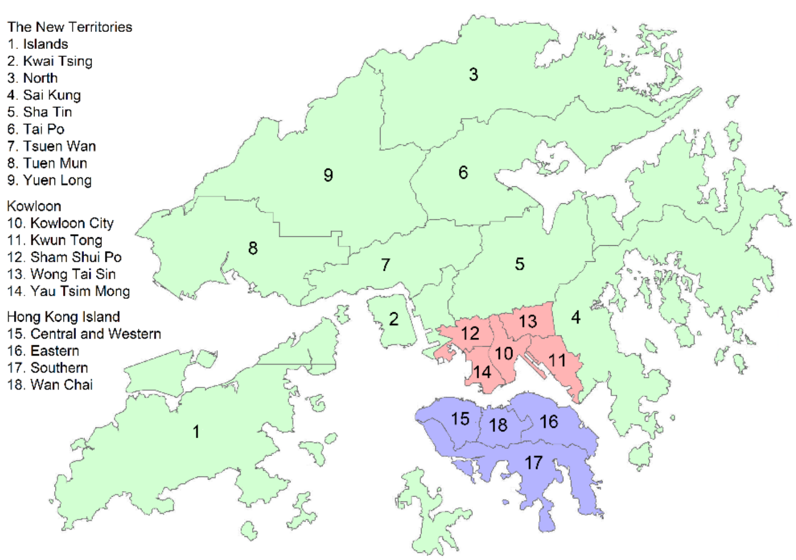

Figure 2 18 zones of the study area

The GPS data during the 2-day (48 hours) tropical cyclone-affected period of Koppu from 6 pm on 13 September to 6 pm on 15 September were extracted. In addition, the data of the same 2-day period in nine other weeks from June to October were also extracted to facilitate the comparison on the taxi availability and ridership, and taxi drivers' customer-search decisions between the extreme weather and normal conditions. 31,740 occupied taxi trips for the 2-day tropical cyclone-affected period, and 38,554 occupied taxi trips on average for the same period in the nine other weeks were obtained for the following statistical analyses.

To conduct the spatial analysis, this study divided Hong Kong into 18 zones as shown in **Figure 2**. The zones in green are the rural areas, and the other zones in red and blue are the urban areas. There are three types of taxis operating in Hong Kong with different service areas. Urban taxis are permitted to operate in all the districts, while New Territories taxis and Lantau taxis are allowed to operate mainly in the rural areas and Island District, respectively. The taxi fare structure is the same throughout the day, without surcharge at night or during peak hours. The travel fares of New Territories taxis and Lantau taxis are charged similarly, but at a lower rate.

RESULTS

The taxi GPS data in terms of the percentage of taxis not in operation, the number of served passenger-trips, the average time spent for vacant taxi drives finding a customer, and the percentage of taxi drivers in cross-district customer-search throughout the two days were extracted to facilitate the comparison between the extreme weather and normal conditions. The taxi data from the nine other weeks were used to plot the upper and lower limits of the 95% confidence interval of normal days based on the associated mean and standard deviation. The limits are used to form a baseline envelope. If the hourly values of taxi availability and ridership, and taxi drivers' customer-search decisions exceed the boundaries of the envelope, it implies that taxi drivers operated abnormally in reaction to the issuance of tropical cyclone warning signals. The following four aspects were investigated.

Proportion of Taxis Not in Operation

The proportion of taxis not in operation is related to the taxi supply level. If the taxi supply is limited, inevitably it adversely influences taxi availability and hence suppresses passenger demand (*27, 28*). **Figure 3** presents the proportion of taxis not in operation during the tropical cyclone-affected period. The blue and orange lines represent the upper and lower limits, respectively, of the data of normal days. On normal days, the proportion of taxis not in operation maintained at a low level (less than 15%) in the day-time, and reached the lowest level in the morning peak at about 9 am. The number of non-operating taxis showed a slight increase in lunch hours, and remained constant with a minor fluctuation until midnight. The number increased dramatically up to around 45–60% between 4 am and 6 am. This was perhaps due to the lower passenger demand after mid-night during which some taxi drivers decided to stop their operation.

The red line represents the data collected during the attack of tropical cyclone Koppu. There was no significant difference in trend between under the normal and extreme weather conditions before the time of issuing the 2-hour advance notice of Warning Signal No. 8 on 14 September. Apparently, most taxi drivers were still operating as usual under the Warning Signal Nos. 1 and 3. The significant increase in the number of non-operating taxis occurred at around 5 pm when the No. 8 Signal was going to be hoisted shortly. Under the effect of tropical cyclone Koppu, the non-operating taxi percentage was about 70% at 10 pm (i.e., about 4 hours after the issuance), which was significantly higher than the percentage of around 15% under the normal weather condition. The number further climbed up to 80% at around 3 am on the following day. It could be deduced that the presence of extreme weather largely decreased the intention of taxi drivers to work. After the time of issuing the 4.5-hour advanced announcement of the cancellation of Warning Signal No. 8, more taxi drivers resumed their business and the non-operating taxis percentage dropped to around 8%. The number remained at a low level during the period where most employees had to rush back to work and returned to normal afterward.

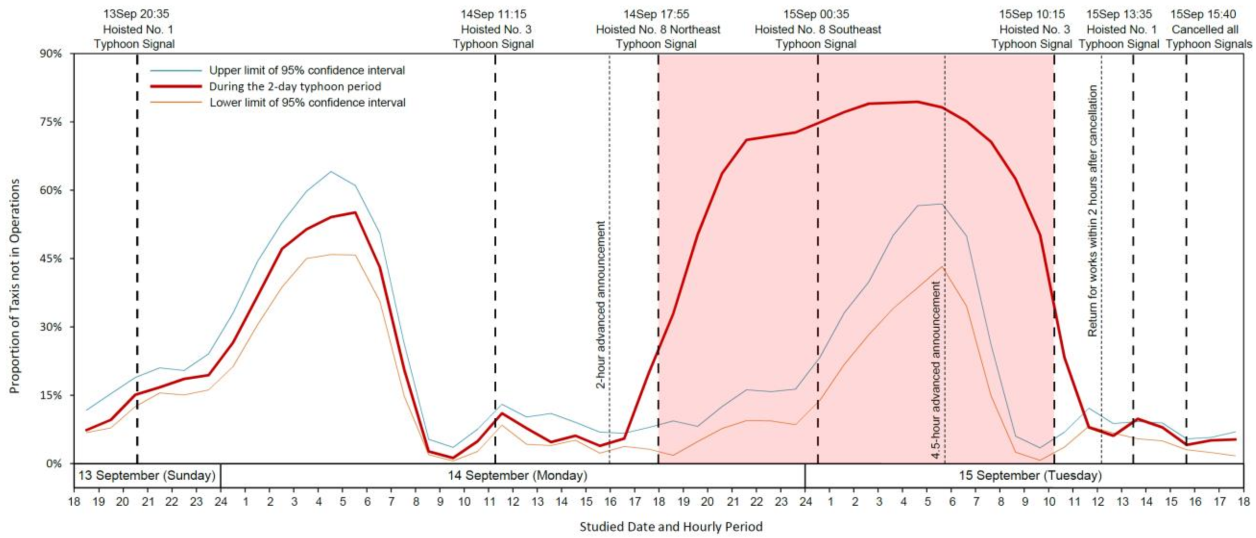

Figure 3 Proportion of taxis not in operation during the 2-day typhoon period

Number of Served Passenger-trips per Taxi

Figure 4 shows the number of passenger-trips made within each 1 hour per taxi, which was calculated based on all 460 taxis considered.Previous studies have confirmed a significant impact of extreme weather on taxi ridership (*21*). Although the number of served passenger-trips does not exactly equal to the real passenger demand with the consideration of unserved passengers, it roughly offers us the trend of variation in passenger demand over the study period.

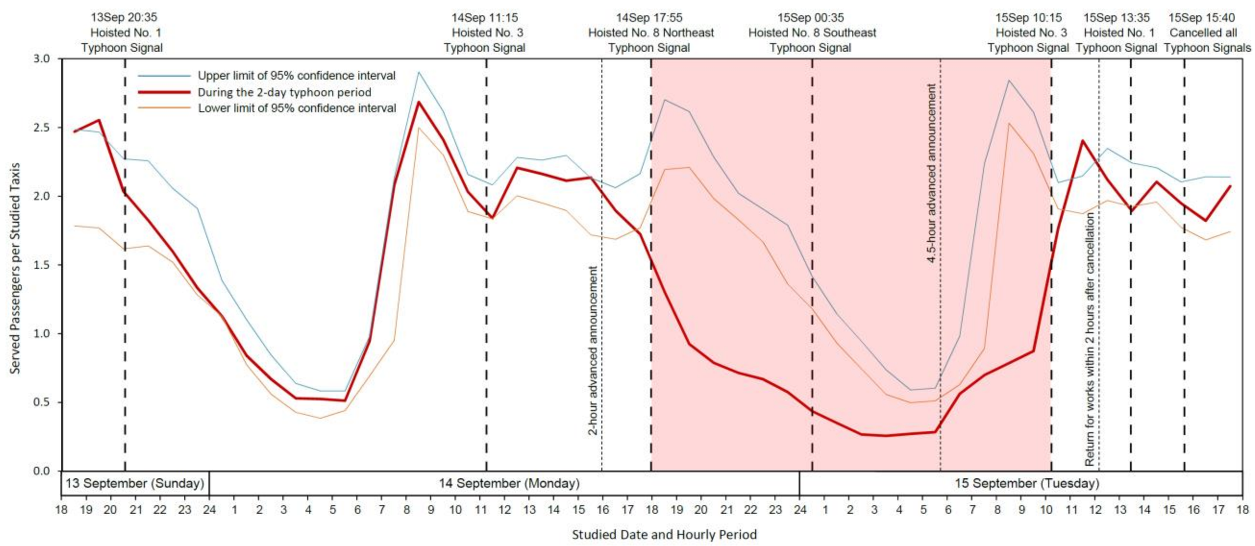

Figure 4 Served passenger-trips per taxi during the 2-day typhoon period

The general trend on studied days without adverse weather followed a common understanding of the trend of served trips. The values were extremely low during midnight to early morning hours between 1 am and 6 am, followed by a sharp increase afterward. The trend reached its morning peak at around 7–9 am. The highest peak appeared at around 8 am with approximately 2.5 to 2.9 served trips per taxi hourly. Trips served then remained stable at around two trips per taxi with a moderate deviation during the day-time before reaching the second peak in the evening hours between 7 pm and 8 pm. The business then dropped gradually between 8 pm to 1 am on the following day.

Before the issuance of Warning Signal No. 3 at around 11 am on 14 September, the number of served passenger-trips per taxi had a similar pattern to that under the normal weather condition. In the following hour, the data showed a slightly sharper increase in served trips. A possible reason could be related to the fact that some of the organizations (e.g., kindergarten) arranged early leave to react with the issuance of Strong Wind Signal No. 3. The number of served trips experienced an immediate drop after around 4 pm, the time of announcing 2-hour advance notice, while the number of served trips started raising at about 4 pm on normal days. After at around 6 pm, the time of the issuance of Warning Signal No. 8, the number of served trips dropped at a faster rate than before. The line continued to plummet from 6 pm to 8 pm while it was the time to reach the evening peak in the normal condition. The line then eased down to a very low level of about 0.3 trip per taxi until around 6 am in the next morning, when Hong Kong Observatory announced in advance that the Warning Signal No. 8 would be replaced with No. 3 in the following hours. The line started picking up at around 6 am. The value then increased quickly at around 10 am–12 noon, in which the typhoon signal was superseded with the No. 3 Signal at around 10 am. The line reached its highest peak at around noon, around 1.5 hours after the cancellation of No. 8 Signal, and this peak exceeded the value of the normal day at around noon. This could be related to the fact that the employees have to return for duties within two hours after the cancellation of No. 8 Signal. However, the peak did not reach to the level of the morning peak on an ordinary day (i.e., over 2.5 trips per taxi), suggesting that passenger demand could be more widespread over time.

Average Customer-search Time of Vacant Taxi Drivers

Figure 5 indicates the average time of vacant taxi drivers (in min) spent on searching for customers in each hour. The average time spent on customer-search is an indicator to reflect the degree of balance between passenger demand and taxi supply. The expected customer waiting time is inversely proportional to the vacant taxi hour and proportional to the demand for taxi rides (*28*, *29*).

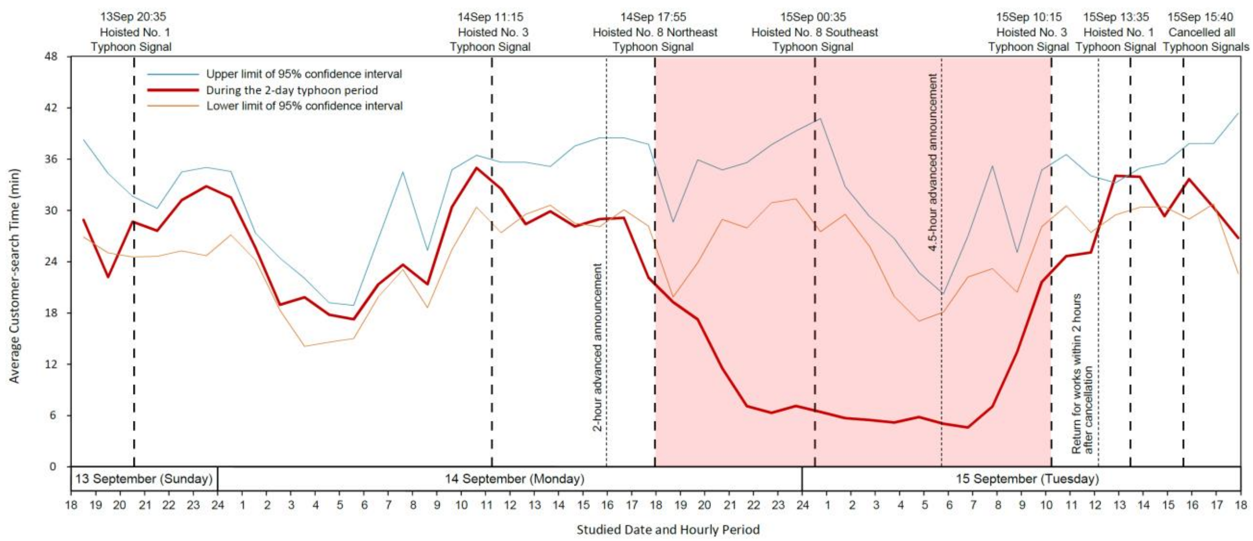

Figure 5 Average customer-search time during the 2-day typhoon period

The intra-day variation on normal days in **Figure 5** was not as significant as that in **Figure 4**. However, the hourly fluctuation was more drastic. The shortest customer-search time always occurred in the early morning hours, when there were much fewer taxis in operation. However, during the day-time, the competition between taxis was fiercer and the average searching time increased considerably.

Within the 2-day study period under the tropical cyclone attacked, the customer-search time showed no significant difference compared with that under the normal weather condition before the time posting the 2-hour advanced notice of Warning Signal No. 8. The customer-search time started decreasing instantly afterward. This could be partly caused by the reduction in the number of operating taxis as demonstrated in **Figure 3**. When there were only 20–30% of the taxis in operation, inevitably taxi drivers were easier to find their customers. On average, only around five minutes was required to get a passenger during the period from 10 pm to 8 am on the following day, which was much lower than that under the normal weather condition. This finding suggested that taxis might not be available in these hours, because passenger demand was much larger than taxi supply. The customers would experience a long waiting time. The searching time started increasing slightly after the time of issuing the 4.5-hour advanced notice of the cancellation of No. 8 Signal. This could be because more taxis resumed their business and joined the competition when the weather was getting better. The average customer-search time increased back to the normal after 2 hours from the time of the cancellation of No. 8 Signal.

Cross-district Searching for Customers

Figure 6 illustrates the decisions of vacant taxi drivers to travel across districts in customer-search. It was estimated based on the zoning system described in **Figure 2**. This aspect reflects that the percentage of drivers who found demand within the district of the previous passenger's destination was insufficient, and decided traveling to nearby districts for business. According to the recent research on time-dependent cross-zonal customer-search behavior of vacant taxi drivers (*23*, *30*), the percentage of cross-district searching is inversely proportional to the corresponding hourly passenger demand.

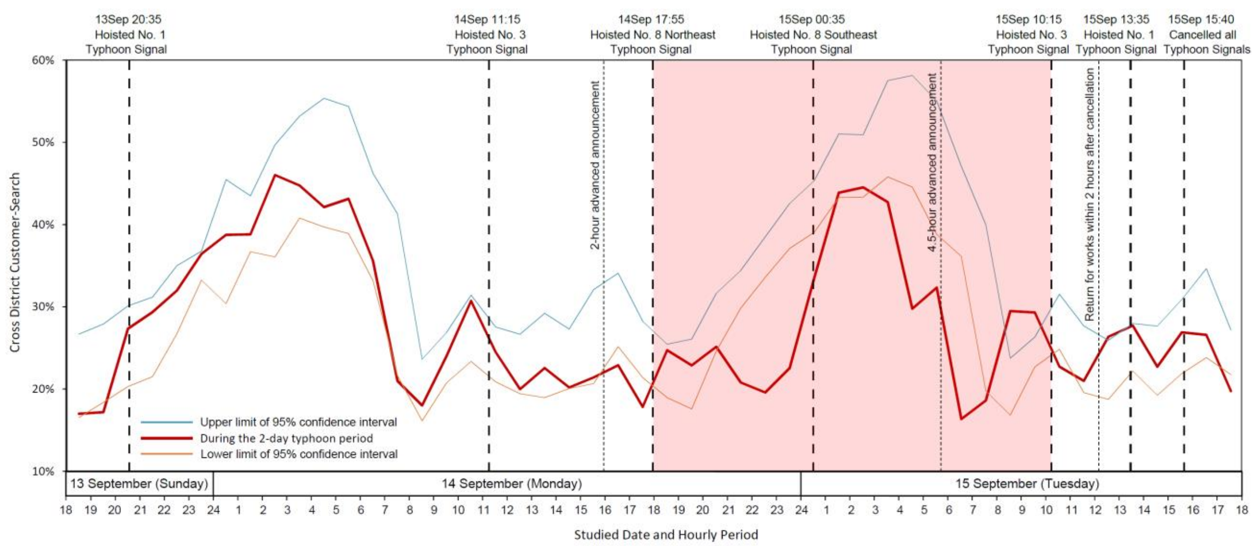

Figure 6 Percentage of cross-district customer-search during the 2-day typhoon period

Under the normal condition, the cross-district searching was generally more common when overall passenger demand was low (i.e., after midnight). A gradual increase in the percentage of taxi drivers in cross-district search could be spotted from 8 pm onwards and climbed up to approximately 40–55%. The percentage dropped obviously until the start of the morning peak and remained low during most of the remaining day-time, although a small variation of the percentage of the cross-district searching, which is due to the variation of passenger demand, can be observed.

The cross-district searching percentage started deviating from the normal level since the time of the issuance of the 2-hour advance notice of Warning Signal No. 8 announced at 4 pm. After around 8 pm, about one and a half hours of the time of issuing the No. 8 Signal, the cross-district searching was slightly lower than that on the normal days. It is discernible that taxi drivers who remained in operation did not travel far to search for customers. The reason may also relate to the unbalance between passenger demand and taxi supply. Evidence from the short customer-search time after around 8 pm, as shown in **Figure 5**, may imply that the original district contained plenty of passenger demand and limited taxi supply. Taxi drivers could then tend to search for passengers within the original district. An abnormal fluctuation appeared in the few hours before the time that employees had to be back to work, suggesting the taxi drivers' anticipation of demand concentration to certain areas and their attempt to seize such opportunities. The following spatio-temporal analysis further investigates this phenomenon.

These four figures show a clear correlation between taxi availability and ridership, and customer-search decisions of vacant taxi drivers. During the attack of tropical cyclone Koppu, a considerable proportion of taxi drivers, who had a concern about their safety and insurance coverage, decided to gradually stop operation as typhoon intensified. This decision could leave more stranded customers facing unexpected waiting time for taxis. The unbalanced demand-supply issues were more interwoven than usual.

Spatio-temporal Analysis of Taxi Ridership

Figure 7 illustrates the spatio-temporal taxi ridership distribution across districts under the extreme weather condition and in normal days. To conduct the analysis, we divided Hong Kong into 18 districts and four representative 2-hour periods, including 1) after the advanced announcement of Warning Signal No. 8; 2) after mid-night when Koppu was the nearest Hong Kong; 3) after the advanced announcement of Warning Signal No. 3; and 4) after the No. 3 Signal was hoisted. The darkness of a district represents the taxi ridership intensity of that district in two hours. The findings reveal that the taxi ridership was higher under the extreme weather condition for periods 1 and 4, where the people were leaving from and returning to work and school before and after the attack of the typical cyclone. In contrast, the taxi ridership was much lower in periods 2 and 3 when Koppu was severely affecting Hong Kong overnight.

During the first study period from 4 pm to 6 pm, the taxi ridership was more evenly distributed as compared to that in normal days. In the typical evening peak period, most of the trips concentrated in the urban areas, especially at Yau Tsim Mong, Central and Western, and Wai Chai Districts. It was probably due to the competition with New Territories taxis and Lantau taxis in the rural areas. The urban taxis had a disadvantage of higher fares in attracting taxi customers (*23*). It also explained the low (urban) taxi ridership in rural areas. After mid-night when Koppu was nearest Hong Kong, the taxi ridership reduced to a very low level in all districts. Comparatively, in the normal days, there was an obviously high taxi ridership at Yau Tsim Mong District, because this district offered more overnight activities and served as a hub of public transport interchanges at night. In the next morning between 5:45 am and 7:45 am, the distributions under the extreme weather condition and in normal days were similar, while the overall taxi ridership was slightly higher in the normal situation. At last, in the period from 10:15 am to 12:15 pm when the No. 8 Signal was replaced, a higher taxi ridership was recorded. It could be explained that most of the employees were requested to get back to the office within these 2 hours, and caused the excessive travel demand.

To compare the spatial distributions of taxi ridership between under the extreme weather condition and in normal days and identify the districts with abnormal taxi ridership, the ratio between the taxi ridership under the extreme weather condition and in normal days was determined as illustrated in **Figure 8**. The ratio was calculated by the number of served passenger-trips in the tropical cyclone-affected period over that in the normal period. The darker district implies a higher ratio, where the districts with a ratio less than one (i.e., the affected taxi ridership was lower) are left blank.

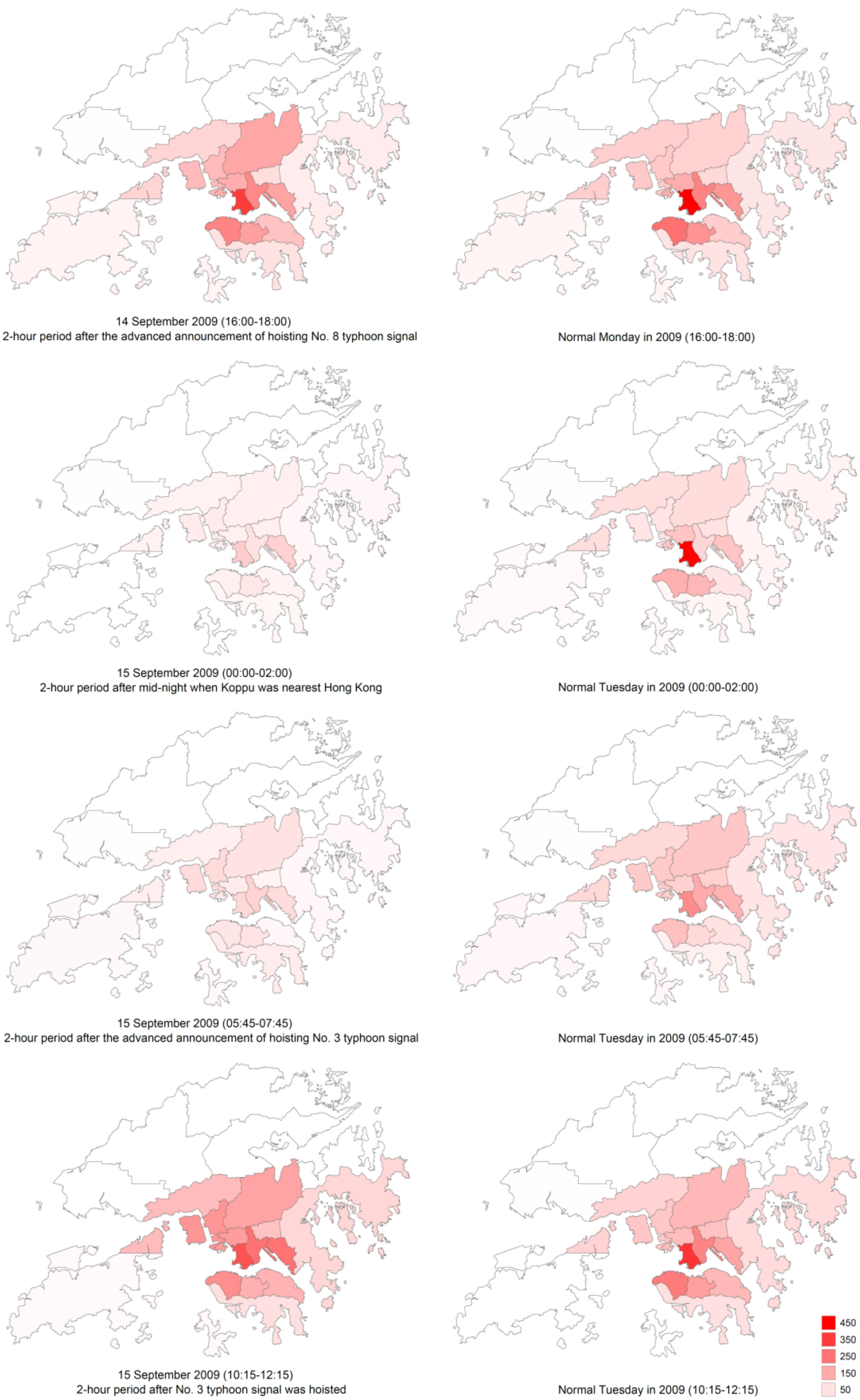

Figure 7 Spatio-temporal distribution of taxi ridership in four concerned 2-hour periods

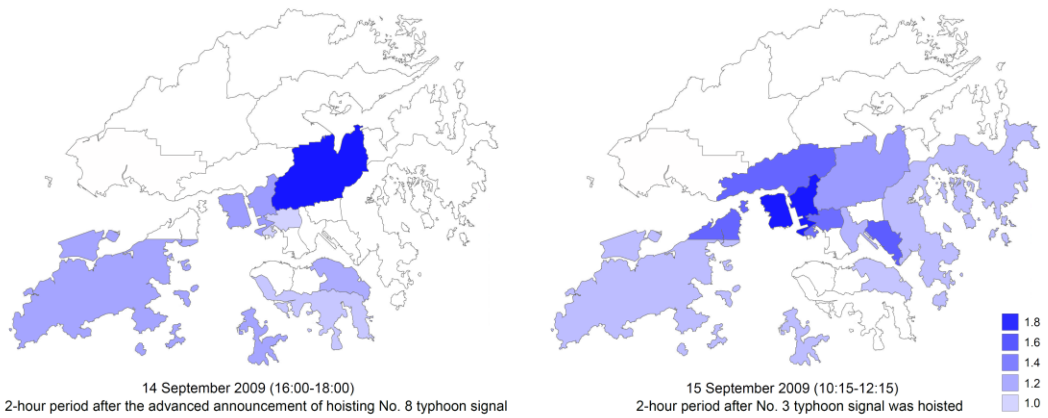

Figure 8 Ratios of affected to normal ridership in two peak 2-hour periods

In the 2 hours before Warning Signal No. 8 was hoisted, the taxi ridership of Sha Tin District was almost doubled with a ratio of 1.90. Other districts posed a high ratio including Kwai Tsing (1.26), Island (1.19), and Eastern (1.19). In contrast, the ratios in Yau Tsim Mong, Central and Western, and Wai Chai Districts were all below one. It is worth mentioning that the typical cyclone-affected period had a lower overall ridership. The affected taxi ridership and normal ridership were 1,882 and 1,970 respectively. It can be concluded that the taxi ridership was more evenly distributed in an extreme weather condition. Then, for the last study period when the No. 3 Signal was issued, the districts having a particularly high ratio were Kwai Tsing (1.89), Kwun Tong (1.56), Tsuen Wan (1.53), and Sham Shui Po (1.49). Again, the taxi ridership at Yau Tsim Mong, Central and Western, and Wan Chai was lower, probably due to the insufficient supply of vacant taxis. The taxi drivers' anticipation of demand concentration to certain areas and their attempt to seize such opportunities. Opposite from the first period (4–6 pm), the total served passenger-trips increased from 1,923 in the normal days to 2,174 in the tropical cyclone-affected period.

KEY FINDINGS AND POLICY SUGGESTIONS

Based on the results in the previous section, we summarize the following three observations that provide policy insights to help to improve the taxi services during an extreme weather condition:

1. A high proportion of taxis (up to 80%) were not in operation, and could not serve the urgent and necessary trips;
2. Taxi trips over-concentrated within short periods before and after the issuance of Warning Signal No. 8; and
3. Expected long waiting time for customers waiting on streets for taxis when the No. 8 Signal is hoisted.

Extended Insurance Coverage to Taxis

Due to safety, legality, and insurance concerns, it is logical for taxi drivers not to operate when the typhoon warning signals are in place. Only limited insurance companies would provide taxi-specific insurance plans in Hong Kong. Under the general clauses, the third-party liabilities are still covered under extreme weather conditions, this is to say that passengers and pedestrians are protected. It is stated that under extreme weather conditions, drivers are responsible for taking safety precautions and measures to ensure the vehicles are operated safely. This clause neither excludes insurers from covering taxi drivers, nor clarifies that taxi drivers are allowed to do business as usual. Arguably, taxi drivers out searching customers under extreme weather conditions may be perceived as "not taking safety measures and not operating under a safe condition". Therefore, the taxi drivers may consider that their risk of being excluded from coverage increases (*31*). It explains why such a large proportion of taxis not in operation during the most adverse period, as shown in **Figure 3**.

Alternatively, taxi drivers could opt for a comprehensive plan that offers wider coverage. However, it is hard to find any taxi insurance available in the market provides special insurance coverage for taxi operations during extreme weather conditions. To tackle this problem, a fixed price annual insurance package is suggested to insure taxi operations under the issuance of tropical cyclone Warning Signal No. 8 or higher. The insurance provides valid third parties insurance and compensation to the vehicle damage with a certain amount of excess caused by extreme weather. Excess is required for each claim to ensure the drivers to take necessary precautions not to expose themselves into high-risk areas deliberately. The proposed insurance scheme reduces the risk the drivers faced thus encouraging more taxi drivers to provide services during the extreme weather.

Standardized Surcharge Imposed During the Extreme Weather

Being currently excluded from insurance coverage has resulted in taxi drivers levying a surcharge on customers to compensate for the risk of operating service when Warning Signal No. 8 or above is hoisted. These surcharges ranged from as low as HK$30 to as high as HK$150 per ride and have become common practice. Nevertheless, such action was clearly declared illegal according to the taxi fare charging system (*32*). Furthermore, there was no agreement whether this surcharge had correctly reflected the risk associated, or in fact, was a mere result of market adjustment initiated by the taxi drivers themselves. Should there be an accident involving taxi drivers that would not be covered by the insurance, the monetary loss would most likely be much greater than the surcharge. Also, customers who had been imposed the surcharge, in most cases, did not have an option. They might have a reservation and avoided traveling under the issuance of Warning Signal No. 8 or above, and highly concentrated to travel within short periods before and after.

To encourage taxi drivers to operate and meet passenger demand during the tropical cyclone, the government can provide an incentive for taxi drivers to operate during the extreme weather by allowing them to charge a higher fare. It is proved that this strategy can boost the supply during inclement weather as the drivers can have an opportunity to earn a higher profit (*33*). Another study has also indicated that the bad driving condition in extreme weather with no compensating differential discouraging drivers from working (*34*). The taxi demand-supply can be more balanced if the taxi drivers receive extra compensation when the demand is higher than the supply (*20, 35*). Therefore, a legal and standardized surcharge is hence recommended. Following the first recommendation, only the taxis with the special insurance covered are allowed to operate and implement the surcharge during the approved conditions. The passengers would be notified about the surcharge before they had boarded a taxi to prevent disputes. The proposed surcharge is considered slightly higher than the current illegal surcharge to encourage more drivers to operate. It secures the profit of the driver and is high enough to cover the cost of the special insurance. Moreover, the surcharge is now legalized which drivers are no longer afraid of violating the law and being prosecuted. Besides, passengers are now fully protected by special insurance. Passengers can travel securely, and most probably it can attract more travelers to select taxis as their travel mean during extreme weather and reduces their dependence on other public transport modes.

Allow Taxi Ride-sharing and Improve Taxi Services in Selected Districts

In addition to a decrease in taxi supply, passengers have to endure a prolonged waiting time. A short average customer-search time during the most adverse period implies that the supply of taxi was insufficient to cater to all the passenger demand. It is therefore proposed taxi ride-sharing during the extreme weather. Taxi ride-sharing allows a taxi transporting multiple groups of passengers with similar itineraries. For the same number of available taxis, more passengers can be served in the given same amount of time. This helps meet the demand of passengers with a limited supply of taxis. Since taxi ride-sharing is currently illegal in Hong Kong, the restriction is proposed to be lifted temporarily when the No. 8 Signal or above is hoisted.

Tropical cyclone normally brings torrential rainfall associated with the strong gale. The reduced visibility and the loosen objects brought up by the wind threaten the safety of customers waiting for taxis on streets especially when the No. 8 Signal or above is hoisted. By matching different groups of passengers into a single taxi ride, it reduces the customer waiting time (*36*). The shorter waiting time implies the customer can take a taxi and travel to a safe place faster and that effectively reduces their risk exposures on streets. In addition, the provision of specialized taxi stands at covered public transport interchange is recommended. It aims to provide a safe environment for both the waiting customers and taxi drivers in selected districts where had a higher taxi ridership as shown in **Figures 7 and 8**. The taxi stands can serve as gathering points for taxi customers and drivers to further improve their meeting efficiency to alleviate the problem of insufficient taxi supply. Moreover, Transport Department and taxi operators are recommended to actively dispatch taxis to the rural and suburban dwellers during extreme weather conditions to serve evacuation trips or trips made during such conditions.

CONCLUSION

Because of global warming, the impact of tropical cyclones and associated heavy rain to the coastal cities in East-Asia will become more and more severe, which certainly causes disruption not only to traffic but also to people's travel options. This study examines how the taxi availability and ridership, and customer-search decisions of vacant taxi drivers correlate with each other when tropical cyclone Warning Signal No. 8 was in effect. We extracted the driving pattern from the GPS data of 460 urban taxis, and compared the taxi operational characteristics temporally and spatially between a tropical cyclone-affected period and normal days in terms of the proportion of taxis not in operation, the number of served passenger-trips, the average customer-search time for vacant taxis, and the percentage of taxi drivers in cross-district customer-search. The findings show that 1) a high proportion of taxis (up to 80%) were not in operation, and could not serve the urgent and necessary trips; 2) taxi trips were over-concentrated within short periods before and after the issuance of Warning Signal No. 8; and 3) expected long waiting time for customers waiting on streets for taxis when the No. 8 Signal is hoisted.

The above results provide some policy insights to improve taxi services during extreme weather conditions. First, this paper proposes an extended insurance coverage to taxis covering the extreme weather condition to reduce the risk faced by the taxi drivers. Second, a standardized surcharge during the extreme weather is recommended providing an incentive for taxi drivers to operate in that situation. Third, this paper suggests a taxi ride-sharing strategy and improvements on taxi services in selected districts by introducing specialized taxi stands and dispatching taxis to increase taxi supply during the extreme weather to reduce the on-street waiting time for taxi customers. A questionnaire survey for taxi drivers should be conducted in a future study to understand what are their main reasons of not operating during extreme weather conditions (because of personal safety, inadequate insurance coverage, or because they are prohibited to operate as the vehicles are not owned by the drivers), and how the expanded insurance coverage and legalized, higher fares sufficiently encourage taxi drivers to continue operation during these events.

Although this paper suggests improving the taxi services for individual emergency transportation needs before, during, and after the extreme weather condition, we do not encourage people ignoring the warning signals and making non-compulsory trips by taxis, which places both the taxi drivers and passengers in potential danger and leads to complacency and unnecessary loss of life. A future study is hence recommended to design and establish an emergency response plan prioritizing and coordinating the evacuation trips, in which taxis provide service in emergencies for personal reasons under a safe condition, and the search and rescue teams of the Fire Services Department are responsible for serious life-saving situations such as severe landfall and flooding.

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AUTHOR CONTRIBUTIONS
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