APPLICATION OF "DRIVESENSE" AND "DRIVEBOX" IN-VEHICLE MONITORING SYSTEM ON WHEELCHAIR TAXI FLEET

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According to The Government of the Hong Kong Special Administrative Region Press Releases, there are 4697 (25.9% of total taxi) wheelchair taxi in Hong Kong as at end of February 2024[1]. Rider comfort is important for the taxi passengers to feel safe and secure, and it is hugely affected by the taxi drivers' driving behavior and attitude. In this study, the wheelchair taxi driver driving behavior will be monitored, recorded and analyzed. It aims to understand the driving performance effects on the subjects of drivers' gender, drivers' age and experiences of driving wheelchair taxi.

In 2023, VTC Smart City Innovation Centre, Hong Kong Institute of Information Technology, and Hong Kong Institute of Vocational Education-Engineering co-developed "DriveSense" in-vehicle monitoring system and "DriveBox" vehicle information logger. "DriveBox" captures vehicles' motion, location and speed once the drivers start the engine. The vehicle information data is transferred to "DriveSense" system through 5G mobile network and stores in cloud-based servers. With intuitive software, vehicle information data has been visualized by presenting in the format of map, graphs and tables. "DriveSense" stands as a pioneering solution, revolutionizing the way vehicle operations are monitored and managed, while ensuring trip safety and riding comfort for taxi passengers.

In 2024, "DriveBox" vehicle information logger has been installed on 8 wheelchair taxis with different vehicle models, such as Toyota Comfort, Toyota Noah 80 and Toyota Noah 90. The barrier-free taxi operator is able to monitor the wheelchair taxi drivers by "DriveSense" in vehicle monitoring System. The analyzed results can proof that female, male or over 60 years old drivers are having capability to be empathic wheelchair taxi driver to provide safely and comfortable trip for disabled passengers.

Keywords: *Vehicle monitoring, wheelchair taxi, disabled passenger, fleet management, driving behavior*

Introduction

Taxi Driver Performance

According to data released by the Government of the Hong Kong Special Administrative Region, as of the end of February 2024, there are 4,697 wheelchair-accessible taxis, representing 25.9% of the total taxi fleet. The number of wheelchair-accessible taxis has been steadily increasing in response to the growing demand from passengers with disabilities who rely on taxis for their daily transportation needs. In 2023, a total of 5,265 taxis were involved in traffic accidents, contributing to 28,808 reported cases across all licensed vehicles, marking the highest accident rate within this category. The report identifies the top five driver-related factors contributing to these accidents as inattentive driving, tailgating, loss of vehicle control, careless lane changes, and improper or illegal turns. Research on risky driving behaviors indicates that the incidence of road traffic accidents can be mitigated through effective enforcement, continuous monitoring, and systematic evaluation. Given that many taxi fleet operators in Hong Kong manage large numbers of vehicles and employ numerous drivers, ensuring consistent and safe driving practices across all drivers presents a significant challenge.

In response to this issue, the VTC Smart City Innovation Centre, in collaboration with the Hong Kong Institute of Information Technology and the Hong Kong Institute of Vocational Education-Engineering, has developed the "DriveSense" in-vehicle monitoring system alongside the "DriveBox" vehicle information logger. These technologies aim to enhance driver oversight and improve overall taxi safety.

The "DriveSense" in-vehicle monitoring system proposes a solution that combines technologies with the existing limitations of the vehicles. It provides users with a vehicle monitoring system requiring minimal modification of the vehicle, allowing users to monitor their vehicles almost in real-time, and alerting the users about the vehicle's status and the drivers' behaviors. In this study, the wheelchair taxi driver driving behavior will be monitored, recorded and analyzed. It aims to understand the driving performance effects on the subjects of drivers' gender, drivers' age and experiences of driving wheelchair taxi.

Convert Barrier-Free Taxis to IoT Vehicles

According to information provided by the Hong Kong Government, as of the end of February 2024, there are approximately 4,700 barrier-free taxis operating in Hong Kong to cater to the transportation needs of passengers with disabilities. These barrier-free taxis are largely similar to conventional vehicles but are equipped with specific modifications, including electric wheelchair ramps, expanded interior space, and secure wheelchair mounting systems to accommodate wheelchair users. Common vehicle models adapted for this purpose include the Toyota Noah 80 Series, Toyota Noah 90 Series, Toyota Comfort, Nissan NV200, and Nissan Serena.

Notably, these barrier-free taxis currently lack integrated smart or Internet of Things (IoT) technologies. To address this gap, the “DriveSense” system has been developed, which integrates sensors, a wireless communication module, and dedicated software to enable the conversion of standard vehicles into IoT-enabled units. This system allows fleet operators to monitor their entire vehicle fleet efficiently through a web-based application. With minimal effort, operators can access comprehensive vehicle data, including real-time location information, thereby facilitating streamlined and effective fleet management.

Materials and Methods or Pedagogy

Hardware Design for Capturing data

“DriveSense” system is combined with the “DriveBox” vehicle information logger. The “DriveBox” (Figure 1) is fabricated by CSS Electronics and comprises a CANbus logger, a 12 V power supply, and a 5G wireless router. The “DriveBox” is used to capture GPS location and vehicle acceleration data. The CANbus logger is combined with the u-blox NEO-M9V-20B GNSS module, the u-blox LARA-R6001D cellular module, and the ATSAMV70N20 microchip. The GNSS module provides IMU data that includes 3-axis acceleration and 3-axis angular rate. The ANN-MS-0-005 GPS antenna is used to receive satellite signals. All captured data will be stored on an SD memory card for batch uploading to the cloud server automatically. Once the batch data file has been uploaded, the file will be deleted automatically from the SD memory card.

Figure 1 Schematic of "DriveBox"

Hardware Installation

The “DriveBox” device is powered by 12V DC through the cigarette lighter socket in the vehicle. The GPS antenna is installed and secured under the windshield for better signal reception. The device will be installed and secured under the driver's seat on a flat surface (Figure. 2). The device will follow the orientation for IMU axis calibration (Figure 3). During the testing period, three car models have been selected to install the “DriveBox” vehicle information logger and captured the driver driving performance data: 1. Toyota Comfort Hybrid (3 vehicles), 2. Toyota Noah 80 (3 vehicles), and 3. Toyota Noah 90 Hybrid (2 vehicles).

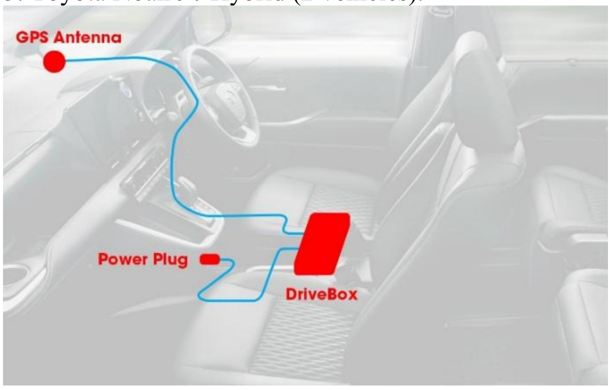

Figure 2 Installation of “DriveBox” in the Vehicles

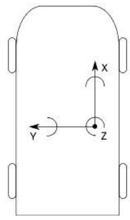

Figure 3 “DriveBox” orientation set-up

Driving Behavior Data Collection

“DriveSense” system and “DriveBox” vehicle information logger have installed on 8 wheelchair taxis, and 20 drivers have been assigned to drive specified taxis from 1 May 2025 to 15 June 2025. Table 1 shows the drivers' list for each taxi. Drivers are assigned to one vehicle only during the data collection period. All collected data will be mapped to the drivers according to the attendance records. Table 1 also lists the drivers’ age range, driving wheelchair taxi experiences, accident records, and the assigned vehicles list. There are 1 driver over 70 years old, 12 drivers between 60-69 years old, 2 drivers between 50-59 years old, and 5 drivers between 40-49 years old. In the testing drivers' team, there are 1 female driver and 19 male drivers. For wheelchair taxi driving experiences, there are 8 drivers with more than 10 years of experience, 8 drivers with less than 2 years of experience, and 4 drivers with between 2-4 years of experience.

Table 1 lists of Driver Information

Driver	Cab number	Vehicle model	Age Range	Driving Wheelchair Taxi Experience (Year)	Accident Rate
Driver A	Cab 3	Toyota Noah 90	40-49	4	1
Driver B	Cab 7	Toyota Noah 90	60-69	15	0
Driver C	Cab 7	Toyota Noah 90	40-49	3	0
Driver D	Cab 5	Toyota Noah 80	70+	15	0

Driver E	Cab 5	Toyota Noah 80	60-69	15	1
Driver F	Cab 2	Toyota Noah 80	50-59	15	1
Driver G	Cab 8	Toyota Noah 80	60-69	15	1
Driver H	Cab 8	Toyota Noah 80	60-69	13	0
Driver I	Cab 8	Toyota Noah 80	60-69	1	1
Driver J	Cab 4	Toyota Comfort Hybrid	50-59	15	1
Driver K	Cab 4	Toyota Comfort Hybrid	60-69	0.5	0
Driver L	Cab 4	Toyota Comfort Hybrid	40-49	4	0
Driver M	Cab 1	Toyota Comfort Hybrid	60-69	0.5	0
Driver N	Cab 6	Toyota Comfort Hybrid	60-69	1	0
Driver O	Cab 6	Toyota Comfort Hybrid	40-49	0.5	0
Driver P	Cab 6	Toyota Comfort Hybrid	60-69	1	0
Driver Q	Cab 6	Toyota Comfort Hybrid	60-69	2	0
Driver R	Cab 6	Toyota Comfort Hybrid	60-69	1	0
Driver S	Cab 3	Toyota Noah 90	40-49	12	2
Driver T	Cab 6	Toyota Comfort Hybrid	60-69	1	0

"DriveSense" System Architecture

The "DriveSense" system consists of "DriveBox" vehicle information logger, cloud server, software design, and a user interface platform (Figure 4). The data will be captured four times per second and saved in a batch file. The batch data file, in MF4 format, will be uploaded to the Minio cloud server through a 4G mobile network. All data will be decoded automatically and stored in another cloud server, the InfluxDB database. The "DriveSense" user interface platform (Figure 5) is designed to be web-based and is able to display all the analyzed driving data on a single page.

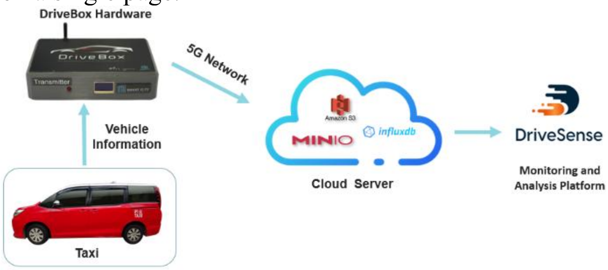

Figure 4 Schematic of "DriveSense" System

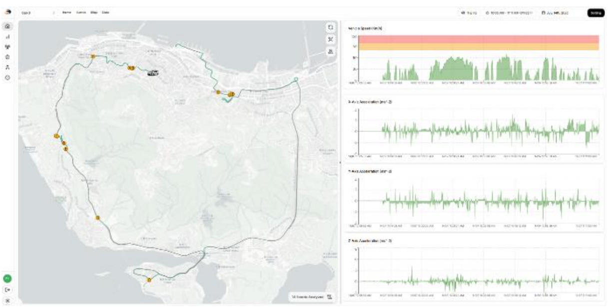

Figure 5 Design of "DriveSense" User Platform

3D Dimensional Acceleration Analysis

The IMU sensor provides three-dimensional motion measurement by converting the detected inertia. Acc-X (X acceleration) value is defined as forward and backward motion; Acc-Y (Y acceleration) value is defined as right and left; and Acc-Z (Z acceleration) value is defined as up and down. The "DriveSense" backend system has set an ACC-X exceeding value of ±3 m/s for the warning alert. The warning frequency for each alert has been set to 4 seconds to avoid repeating alerts.

Speeding Analysis

The speeding analysis uses recorded GPS ground speed values and the "Road Networks (2nd Generation)" data set from the Hong Kong Transport Department to identify the driver's speeding behavior. The speeding identification has been set if the vehicle is over 7 km/h. The speeding alert frequency for each alert has been set to 10 minutes to avoid repeating alerts.

Trip Determination and Trip Distance Calculation

Every 0.25 seconds, one set of data points will be recorded, and it will be used to calculate the distance. The total trip distance is calculated using the equation of speed x time (0.25 seconds). The total distance will only be calculated when the GPS signal is available. The total driving time will be calculated from when the GPS signal is received until it is lost. If the GPS signal is lost for more than 60 seconds, a new trip is set up.

Results and Discussion

Total Driving Distance and Total Driving Duration

Results (Figure 6 and Figure 7) show the driving records for each driver from 1 May 2025 to 15 June 2025. During the data collection period, data on the driving behavior of 20 drivers have been collected. The highest driving distance and duration are 3957.4 km and 12426 minutes by Driver A. The lowest driving distance and duration are 104.77 km and 453 minutes by Driver R. The average driving distance and duration for the drivers are 1777.0 km and 5438.95 minutesRemember the followings: do not end a page with a heading, do not start a page with an incomplete line, do not underline any part of the text, and do not forget to check the spelling.

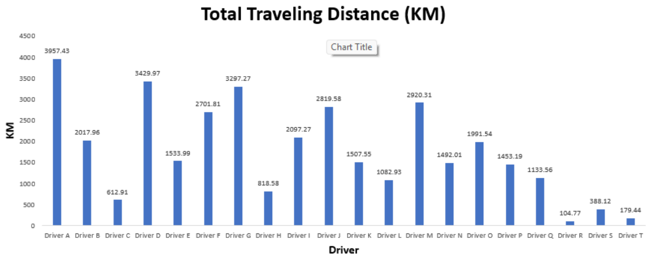

Figure 6 Results of Total Traveling Distance for Drivers

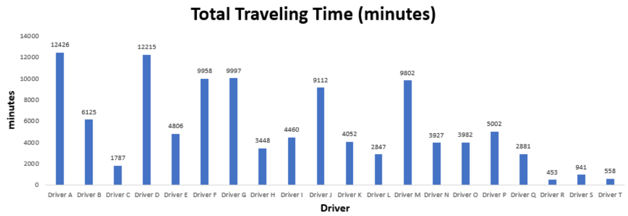

Figure 7 Results of Total Traveling Time for Drivers

Driving Behavior Analysis

"DriveSense" has captured driving behavior data from different drivers and analyzed it. Figure 8 shows the number of driving alerts for each driver along with different types of alert distribution. It has been found that Driver A has 2008 driving alerts, which is the highest. Driver R has 53 driving alerts, which is the lowest. The results do not indicate that high driving mileage corresponds with a high driving alert rate. The driving alert rate is based on the driver's driving behavior. Results also shows that the alerts are mainly due to rough steering, such as fast left turns or right turns (Figure 8). Approximately 70% of total driving alerts are attributed to rough steering. Additionally, about 20% of total driving alerts are due to heavy braking.

Results shows the frequency of driving alerts for each driver, which is the number of driving distances that will occur per driving alert (Figure 9). Higher values mean that the driver has a low driving alert frequency, and the driver is considered a safe driver. Driver H has the lowest driving alert frequency at 9.2 km per alert, while Driver L has the highest driving alert frequency at 1.25 km per alert.

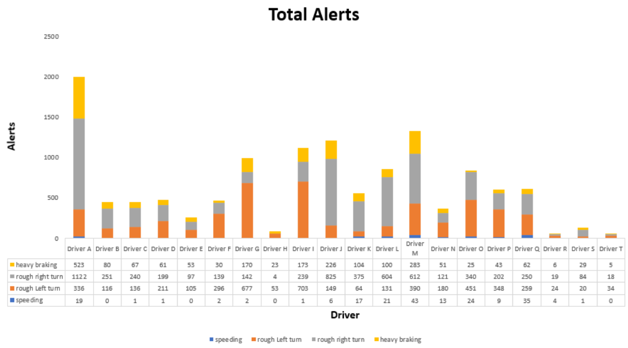

Figure 8 Results of Driving Performance Distribution for Drivers

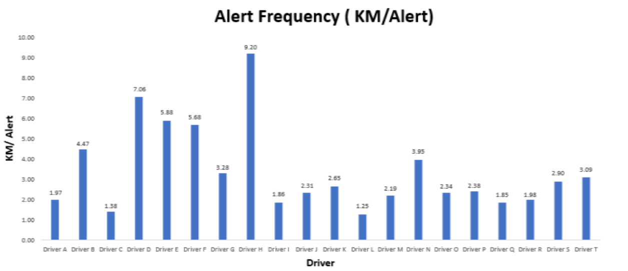

Figure 9 Results of Alert Frequency for Drivers

Gender of Wheelchair Taxi Driver

The results show that there is little difference in terms of driving behaviour for different gender. Driver F is a female driver and she has an alert frequency of 5.68 km/alert. Compared to other drivers, Driver F's frequency value is above the average value of 3.38 km/alert. The results shows that Driver F has good practice in controlling the brake panel (Figure 8). She has the lowest heavy braking alerts rate during a 2700 km driving distance, which is about 90 km per heavy braking alert. Heavy braking in a wheelchair taxi can cause serious injury for disabled passengers. Common injuries include whiplash, concussions, broken bones, and in more serious cases, traumatic brain injuries, spinal injuries, and even amputations. Many passenger transportation companies are very concerned about heavy braking, and provide training to drivers for braking control. Therefore, the results can prove that all gender can be an empathetic wheelchair taxi driver with good controlling of the vehicle.

There are 5 drivers over 60 years old who have an alert frequency value above the average value of 3.38 km/alert (Figure 9). Driver B, Driver D, Driver E, Driver H, and Driver N would be considered older empathetic wheelchair taxi drivers. It is usually the case that older drivers have more driving experience than younger drivers. However, older drivers may have a slower reaction time than younger drivers, which could increase the risk of accidents. The results can prove that older drivers can maintain a good driving attitude to avoid car accidents. A very small number of car accidents have been recorded in the past 10 years or even more. Therefore, it can be believed that if older wheelchair taxi drivers have a good driving attitude and patience, he or she could be a good empathetic and safe wheelchair taxi driver.

Over 10 Years Experienced Wheelchair Taxi Driver

Driving experience significantly influences driving performance. The findings indicate that drivers with extended driving experience demonstrate superior control over the brake pedal, accelerator, and steering. Within the study, eight individuals were classified as experienced wheelchair taxi drivers, each possessing over ten years of experience in this specific domain. These drivers include Driver B, Driver D, Driver E, Driver F, Driver G, Driver H, Driver J, and Driver S. The majority of these experienced drivers exhibited a high alert frequency rate, surpassing the average value of 3.38 km per alert as illustrated in Figure 9. Nonetheless, Drivers J and S displayed marginally lower driving performance despite their extensive experience. This suggests that multiple factors beyond experience—such as the driver's personal background, financial motivations, and personality traits—may impact driving behavior. A prevalent issue among Hong Kong taxi drivers is the pressure to increase income, which often leads to faster driving speeds in order to complete more trips within a given timeframe.

An exceptional case is Driver N, who demonstrated commendable driving performance with an alert frequency of 3.95 km per alert, despite having only one year of experience driving a wheelchair taxi. This anomaly is attributed to the transferability of driving skills from related fields; Driver N is a retired ambulance driver with over ten years of experience operating emergency vehicles. Consequently, it can be inferred that extensive driving experience, whether directly related or transferable, contributes positively to driving performance.

Conclusions

The "DriveSense" system, in conjunction with the "DriveBox" vehicle information logger, enables comprehensive monitoring, storage, and analysis of driver behavior across eight wheelchair taxis.
This integrated monitoring framework facilitates remote management of both vehicles and drivers by taxi fleet operators. Analysis of driving performance data from a sample of 20 drivers yields several key findings: (1) gender have no effect in the capacity to provide empathetic service as wheelchair taxi operators; (2) individuals aged over 60 years can safely operate wheelchair taxis, given their physical and mental health conditions allow; and (3) drivers possessing greater driving experience exhibit superior driving performance. Looking ahead, it is recommended that the deployment of the "DriveSense" monitoring system and "DriveBox" logger be scaled up to encompass to larger fleet or other fleet vehicles. This would enhance the efficacy and quality of vehicle monitoring services available to other fleet management companies while most importantly, ensuring the health and safety for the passengers.

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