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A New Era of Black Box – Refreshed Approach via Latest Technologies and the Challenges

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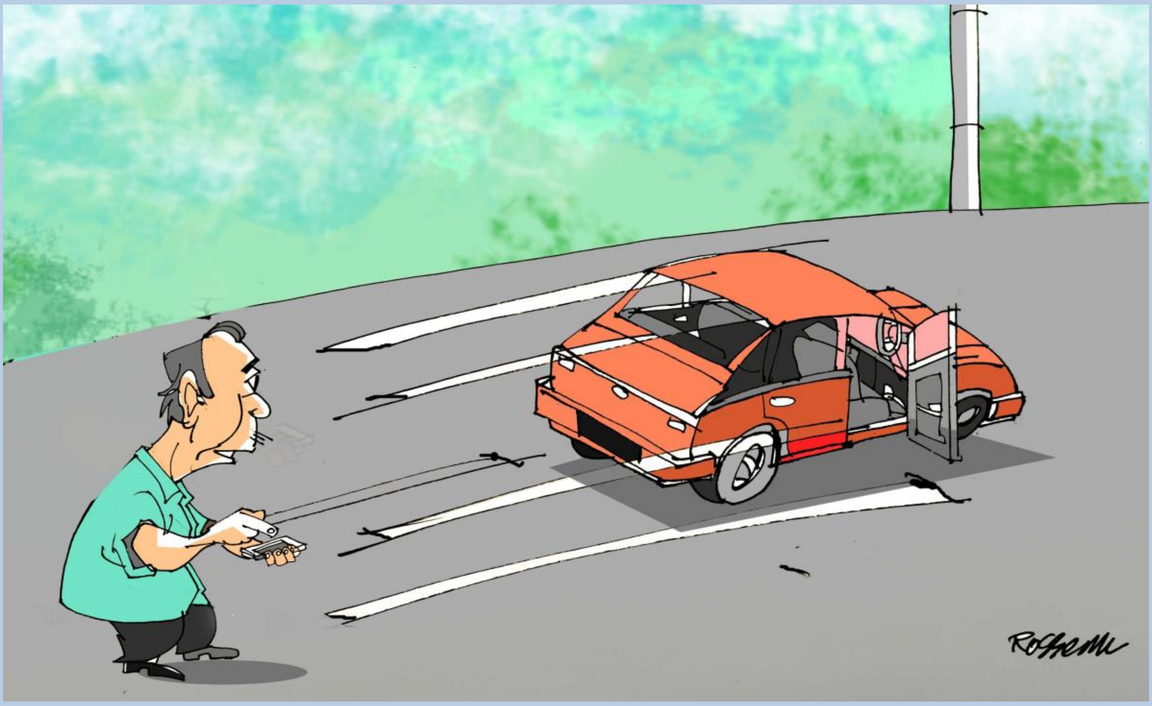

Generally used in aircraft to record and store operational data, the black box has also been used in road vehicles, either commercial or private, for safety, control, and investigative mechanism. Technological advancements have allowed the development of data-generating items in modern-day cars such as EDR and dashcams. Despite their benefits in road safety especially in vehicular forensics, there are concerns about safety, privacy, and users' rights. This warrants refreshed approaches to gradually embed a digital culture into the existing automotive ecosystem. They include a collaborative effort to create an inclusive discussion among a group of local experts recognized as the Modern Vehicle Expert Consortium (MOVE), and a review of related laws and regulations to protect the end users, government, and related stakeholders.

Graphic: Rossem or his real name, Rosidi Semail, is a legendary cartoon artist currently based in Ketereh, Kelantan, Malaysia. He has a gallery named Balai Kartun Rossem and his Facebook page is www.facebook.com/rossem.sem.

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The Black Box

In general, the black box refers to the device that stores the vehicle's operational data. Many will relate the device to a flight recorder that records vital information including cockpit conversation which will be very beneficial, especially in case of a mishap (Kassem et al., 2008). The same idea applies to road transportation and has previously been emphasized among commercial vehicles (buses and Heavy Goods Vehicles - HGVs) as a safety, control, and investigative mechanism (Lehmann & Cheale, 1998; Kowalick, 2005). Nevertheless, the black box technology in the previous decade may not be as good as today's since the latest design is very compact, more precise, able to store large data, and be connected to the Internet or cellular network.

For drivers, this advancement can either be a piece of good news or a bad one. The data, in many forms, can be a source of protection for them since the evidence is secure and in digital form. However, those data also can be used against them when they are at fault (Chae et al., 2010). At the same time, the latest black box technology is also beneficial to researchers, enforcers, investigators, reconstructionists, and insurers (Guzek & Lozia, 2002; Chung & Chang, 2015; Porrini et al., 2020; Ariffin et al., 2021).

In terms of terminology and nomenclature, there is a confusing and interchangeable use of names to refer to certain types of black boxes. For example, the term 'EDR' which refers to Event Data Recorder is also used for dashcams (Figure 1) (Ariffin et al., 2021; Ahmad et al., 2022). Additionally, the term dashcam, which is a portmanteau of 'dashboard camera', is also known as a car digital video recorder (Car DVR), driving recorder, and also car CCTV (Closed Circuit Television) (Chae et al., 2010; Ariffin et al., 2021). Other reports also referred to the black box as Vehicle Black Box (VBB) (Chung & Chang, 2015), Vehicle Black Box System (VBBS) (Kassem et al., 2008), Motor Vehicle Event Data Recorders (MVEDR) (Chung & Chang, 2015), and black box referring to EDR in Figure 1 (Kopencova & Rak, 2020).

FIGURE 1 – EDR unit and the setup to retrieve data from a crashed car (Ahmad et al., 2022)

Data Generation

Figure 2 illustrates the technological advancements in modern-day cars and their vulnerability to being compromised – though the information might not be comprehensive of what's available. According to Bates (2019), modern cars create a large amount of digital data from about 75 Electronic Control Units (ECUs) that store 150 million source codes and generate about 25 GB of data for an hour of operation. From another point of view, we can divide these data-generating items in cars into four categories as in Table 1 (Lacroix et al., 2016; Bates, 2019); Oviedo-Trespalacios et al., 2019; Kopencova & Rak, 2020; Le-Khac et al., 2020). First, the system is already embedded in the car – there might be different offerings for a specific model through model variants as standard fit or option. The second one is the devices installed by the owner or normally referred to as aftermarket devices. Certain items such as dashcams can have either of these statuses, and we can consider add-ons by the traders/sales centers as having the aftermarket status. Third, is the key fob that belongs to a car but will be in and out of the car (except for keypad and biometric entry). The same goes for the fourth category that one will bring in and out of cars, which are the gadgets or data storage that we usually connect to the infotainment system.

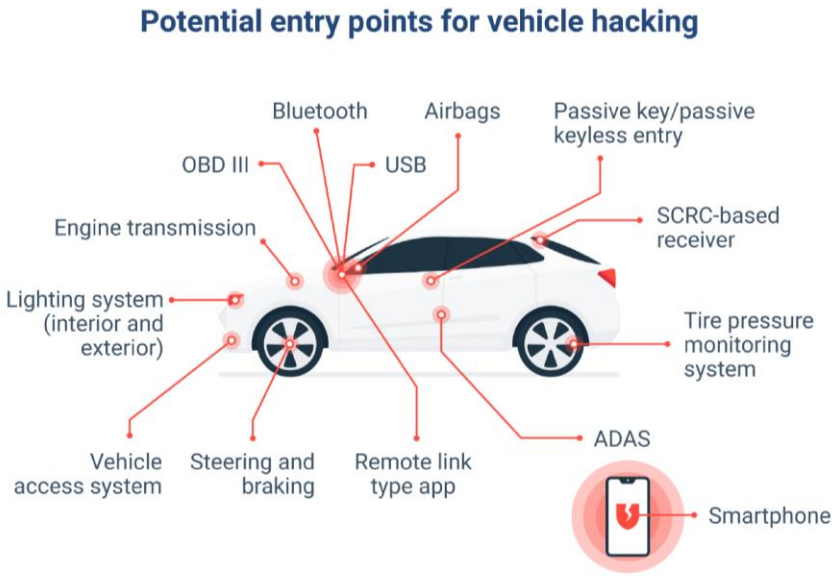


FIGURE 2 – Potential entry points for vehicle hacking (www.dynastync.com)

TABLE 1 – Data-generating items in cars

Category	Explanation
In-car devices and systems	• EDR, e-Call (built-in), infotainment system, etc. • Miscellaneous systems/sub-systems with the ability to store data/logs. • For EDR – drivers have no direct control of the data while in normal usage; some may not be aware of its existence. • EDR records 5-second data before a crash – access via a diagnostic scanner/scan tool (OBD – onboard diagnostics). • e-Call can also be activated manually.
Aftermarket devices installed in a car	• Purpose-built black box, GPS, dashcam, etc. – with data storage capability. • Latest dashcam models come with apps on smartphones; hence data can also be found on the phone. • Journey logs help business to control fleets and optimize operations (reduce paperwork, movement analytics, theft-and-abuse deterrence, etc.).
Car key ***(In and out of the car)***	• Key fob a.k.a. smart key. • Digitally identifying the car's VIN (Vehicle Identification Number). • Stores vital data, e.g., timestamp of last usage, key transponder ID, odometer status, number of paired keys, fuel status, etc.
Gadgets/devices/data storage brought in a car and connected to the car's system(s) ***(In and out of the car)***	• Smartphones, tablets, laptops, USBs, SD cards, etc. • Normally connected to the infotainment system (also referring to the automotive head unit or the In-vehicle Information Systems – IVIS). • Connectivity via Wi-Fi, Bluetooth, etc. • Phone integration based on iOS or Android phones, i.e., Apple CarPlay and Google Android Auto.

Vehicular Forensics

The black box can significantly reduce the cost of accident investigation (both money and time), as well as crash reconstruction and related forensics works (Chae et al., 2010). Based on the traditional approach, one could not technically gather "all shreds of evidence" at the crash site due to many limitations. Even with all the collected evidence at hand, the final analysis most of the time should not be considered "absolute" findings as we normally apply the "benefit of the doubt" concept and present the result in range estimation. Other challenges are unknown parameters, pending further data collection, and loss of evidence due to many circumstances (e.g., rain, stolen, ruined, etc.) (Figures 3 and 4) (Jawi et al., 2015; Abidin et al., 2022). In this context, digital evidence including audio and video recordings is already in the absolute category of evidence (similar to the likes of blood tests, DNA tests, fingerprints, etc.) (Le-Khac et al., 2020) – but still needs confirmation on its originality and untampered status, especially for use in court and insurance claims.

Figure 4 portrays the importance of digital evidence in enriching the buildup of a case, especially when explaining the sub-events in a crash with regard to the three crash main stages – vehicle collision, human collision, and internal collision (human body). For example, dashcam footage that recorded the car's internal area would give a piece of early evidence to the investigator/reconstructionist regarding human collision (Ariffin et al., 2021), which previously had slim to no chance of assessing the victim(s) and need some time to obtain a report from the medical side (sometimes to no avail). The EDR, on the other hand, will definitely secure loads of data from ECUs five seconds prior to impact (Figures 5 and 6). Both dashcam and EDR can be considered absolute evidence (pending originality/untampered confirmation) and eventually supersede the traditional way of doing crash reconstruction (e.g., analyzing sub-events that sometimes include guesswork/speculation, and depending on victim/witness statement or even news reports in the case buildup) (Donnelly et al., 2001; Gabler et al., 2003; Jawi et al., 2015; Manuel et al., 2018).

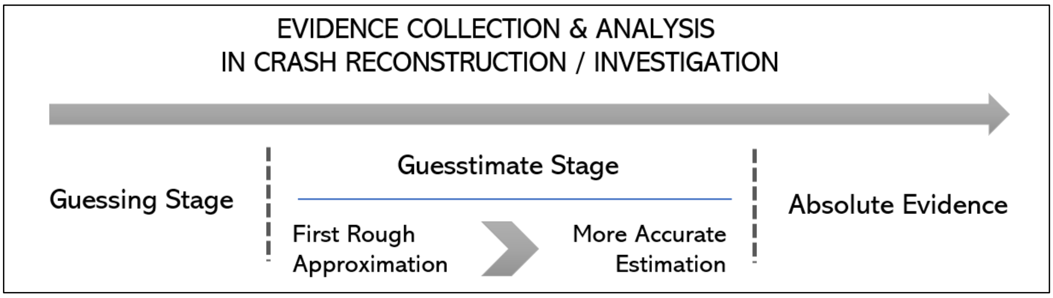
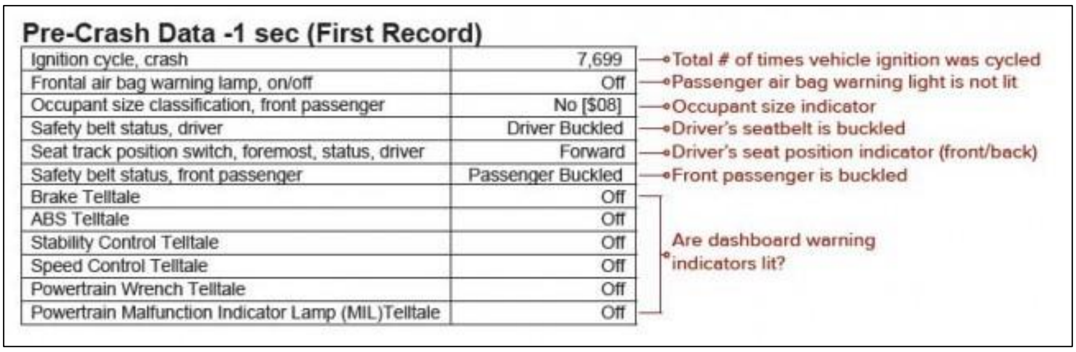


FIGURE 3 – Progression of evidence collection and analysis in crash reconstruction/investigation

Time Line →						
		Crash Event				
Start of Journey	***Pre-Crash***	***Point of No Escape***	***Point of Actual Perception***	***Point of Operator Action***	***CRASH***	***Post-Crash***
> Time of departure	> Passenger anecdote > Passenger perception on driving behavior	> Speeding (perceived)	> Driver attempt to avoid collision with other vehicle > Lane changing	> Lost control	> Crash sub-events (from encroaching the median until the end) > Time of crash	> Final rest position > Rescue effort > Casualties & trauma care

FIGURE 4 – Chronological order of a crash; an example of extracting a news report (Jawi et al., 2015)


Pre-Crash Data -1 sec (First Record)

Ignition cycle, crash	7,699
Frontal air bag warning lamp, on/off	Off
Occupant size classification, front passenger	No [$08]
Safety belt status, driver	Driver Buckled
Seat track position switch, foremost, status, driver	Forward
Safety belt status, front passenger	Passenger Buckled
Brake Telltale	Off
ABS Telltale	Off
Stability Control Telltale	Off
Speed Control Telltale	Off
Powertrain Wrench Telltale	Off
Powertrain Malfunction Indicator Lamp (MIL)Telltale	Off

FIGURE 5 – Example of EDR data (-1 sec) (Leiss, 2015)

Countdown leading to initial crash pulse

Pre-Crash Data -5 to 0 sec [2 samples/sec] (First Record)

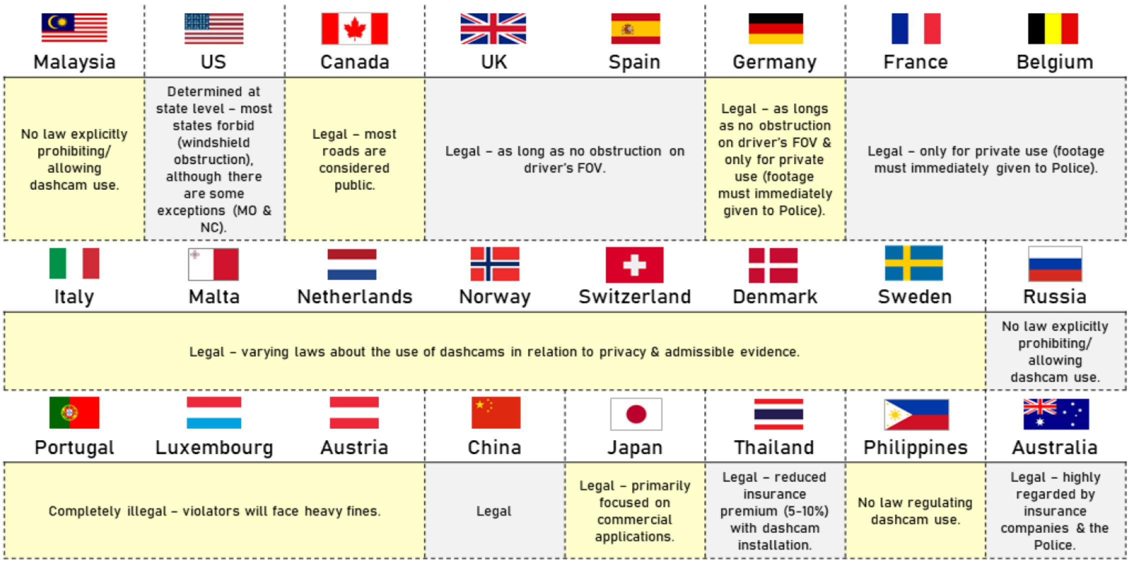
Times (sec)	Speed vehicle indicated MPH [km/h]	Accelerator pedal, % full	Service brake, on/off	Engine RPM	ABS activity (engaged, non-engaged)	Stability control (engaged, non-engaged)	Traction Control via Brakes (engaged, non-engaged)	Traction Control via Engine (engaged, non-engaged)
- 5.0	42.9 [69.0]	0	On	1,100	non-engaged	non-engaged	non-engaged	non-engaged
- 4.5	40.4 [65.0]	0	On	1,000	non-engaged	non-engaged	non-engaged	non-engaged
- 4.0	38.5 [62.0]	0	On	1,000	non-engaged	non-engaged	non-engaged	non-engaged
- 3.5	36.7 [59.0]	0	Off	900	non-engaged	non-engaged	non-engaged	non-engaged
- 3.0	35.4 [57.0]	9	Off	900	non-engaged	non-engaged	non-engaged	non-engaged
- 2.5	35.4 [57.0]	19	Off	1,100	non-engaged	non-engaged	non-engaged	non-engaged
- 2.0	34.8 [56.0]	21	Off	1,800	non-engaged	non-engaged	non-engaged	non-engaged
- 1.5	35.4 [57.0]	24	Off	1,900	non-engaged	non-engaged	non-engaged	non-engaged
- 1.0	35.4 [57.0]	24	Off	2,000	non-engaged	non-engaged	non-engaged	non-engaged
- 0.5	36.0 [58.0]	24	Off	2,000	non-engaged	non-engaged	non-engaged	non-engaged
0.0	36.7 [59.0]	23	Off	2,000	non-engaged	non-engaged	non-engaged	non-engaged

engine speed
were safety systems activated?
brake pedal pressed?
% throttle pedal applied
pre-impact vehicle speed

FIGURE 6 – Example of EDR data (-5 to 0 sec) (Leiss, 2015)

Collaborative Effort: MOVE Consortium

On 7 September 2020, the then Transport Minister of Malaysia, Ir. Dr. Wee Ka Siong (Datuk Seri), responded to an earlier suggestion by academia to make dashcams available to entry models regardless of model variants (message intended for national cars, i.e., Proton and Perodua) (Mat Ruzki, 2020). He also mentioned what was reported by Ariffin et al. (2021) that more studies were needed regarding the use of dashcams, especially with regard to enforcement and the usage of evidence in the court of law. Dr. Wee Ka Siong also affirmed that the law right now is rather vague when it comes to the usage of dashcams as a safety device (Figure 7) (Ariffin et al., 2021).



Note: FOV – Field of view

FIGURE 7 – Comparison of dashcam legality between countries (Ariffin et al., 2021)

Below is the most notable part of Dr. Wee Ka Siong's statement (Mat Ruzki, 2020):

> *"I won't argue with the view that dashcams will be a burden to users, especially those from the B40 group if we make dashcams a mandatory item. It (the footage) can be used in court or for other purposes, and it can be used as an educational avenue, but we shouldn't look at it as deterrence as of now in terms of road safety."*

His last point on “deterrence” relates to the law and the need for a strategy to gradually embed a digital culture into the ecosystem – and to sound politically correct in front of the press. In reality, several ministries have already moved towards high-tech enforcement through their agencies, meaning digital evidence has nowadays become a must. For example, the camera-based enforcement for speed and traffic lights is already in operation (it was initially branded as “AES”, and later rebranded as “AwAS”) (Isah et al., 2015; Ab Rashid et al., 2021). Today, the government also is equipping other devices or systems such as body cam, helmet cam, and weigh-in-motion (WIM; High-Speed WIM – HS-WIM; Integrated WIM – i-WIM) mainly for detecting overloading offenses (Malek & Nordin, 2017; Hussin, 2019; Foong, 2022).

The Malaysian Institute of Road Safety Research (MIROS) of the Ministry of Transport Malaysia (MOT) and CyberSecurity Malaysia (CSM) of the Ministry of Communications and Multimedia (K-KOMM) started the collaboration work in early 2021. The former is known for its expertise in crash reconstruction and crash testing (Kassim et al., 2018), and the latter is very well known for cybersecurity matters (ranked among the top globally) (Culpan, 2021). About a year later, both agencies signed a Memorandum of Cooperation (MOC) in Melaka to signify the importance of working on the subject of vehicular digital data and evidence (CSM, 2022b; MIROS, 2022).

For the sake of national interest, MIROS and CSM should work in tandem, especially to face new challenges brought by modern cars and not to mention the rapid growth of Electric Vehicle (EV) and Autonomous Vehicle (AV) that are heavily studded with electronics and digital systems. CSM has created a project called ‘CamKenderaan’ (verbatim meaning: detecting-vehicle) to first and foremost explore digital forensics techniques and methods on vehicle-related systems (Figures 8 and 9). The project is backed by the government through the Twelfth Malaysia Plan (12MP or RMK-12; under *“Pengukuhan Keupayaan Forensik Siber Negara”*) and is expected to help all parties including enforcing agencies such as Road Transport Department (RTD/JPJ), Land Public Transport Agency (APAD) and Royal Malaysia Police (RMP/PDRM). The involvement with APAD will benefit the commercial vehicle segment (buses and HGVs), especially the fleet management system (FMS).

FIGURE 8 – CamKenderaan project logo by CSM (left); MOVE logo (right)

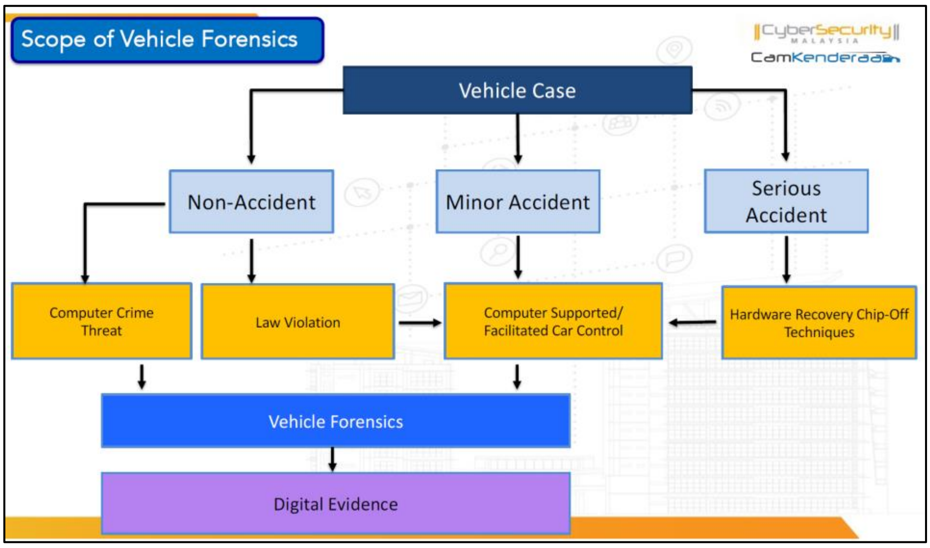


FIGURE 9 – Scope of vehicular forensics under CSM’s CamKenderaan

Moreover, CSM and MIROS also wished to create an inclusive environment among the think-tanks, so a study group was created to discuss current issues and future scenarios through regular physical and virtual meetings (e.g., Hanif, 2022). Recognized as the Modern Vehicle Expert Consortium (MOVE) (Figure 8), the group is opened to all interested experts (at an individual level) and has been able to attract people from academia, automotive industry experts, legal practitioners, and senior motoring journalists.

CSM is also currently working with local researchers mainly from the Universiti Malaysia Pahang (UMP), KATSANA (telematics/fleet management), and MIROS in developing the aftermarket black box under a project called CamKenderaan *Kotak Hitam* (meaning: black box). The project will include related expertise such as CAN data extraction, whole car data collection, harsh detection and movement data, crash detection, as well as scenarios development including speeding, fraud claim, and driver behavior (CSM, 2022a).

The above-mentioned endeavors will not only be aiming at protecting the end users but also facilitating better preparation and changes in the ecosystem in several ministries and agencies such as MOT (road transport), K-KOMM (communication technology), MITI (trades and industries), KDN (internal affairs/police/immigration), MOTAC (tourism), MOH (health), MOW (infrastructures/ITS), and so on. Thus, the following acts, documents, and plans are in the spotlight:

- Road Transport Act (RTA; Act No. 333), related road transport rules *(Kaedah-kaedah Pengangkutan Jalan)*, and Land Public Transport Act (Act No. 715).
- Police Act (Act No. 344), Evidence Act (Act No. 56), etc.
- National Transport Policy (*Dasar Pengangkutan Negara* – DPN)
- Malaysia's Road Safety Plan (*Pelan Keselamatan Jalan Raya Malaysia* – PKJRM)
- National Automotive Policy (NAP) (MITI, 2020)
- Malaysian ITS Blueprint (MOW, 2019)

Moving Forward

The progression in modern cars is largely intended to offer safer, more efficient, and user-friendly mobility to drivers and their passengers (Lacroix et al., 2016). However, there are concerns about their safety due to external attacks, data privacy, and how the digital data generated can be in their favor or against them in case of a mishap. In general, the entire ecosystem must strike a balance between the right of users and the governance issues that enforcers, investigators, and insurers face. As mentioned by Kopencova & Rak (2020), vehicular digital forensics is an emerging area that needs serious advancements in terms of standardization (globalization) of data interface, recording-storage capability, as well as affordable and user-friendly forensic methodologies. From an R&D point of view, the following can be done at the domestic, regional, and international levels from Malaysia's perspective (some of these issues were discussed at the Pre-MOVE Forum at Everly Hotel, Putrajaya (Hanif, 2022)):

Domestic level:

- Review the national plans, laws, and regulations/rules related to vehicular digital data, e.g., Road Transport Act and all the above-mentioned documents.
- Assist consumerism concerns among automotive users – in modern cars, ridesharing/delivery-courier, aftermarket devices, ethics, psychological issues, etc. (Ibrahim et al., 2018; MITI, 2020; Ariffin et al., 2021). More studies on usage behavior are required to better understand the local context – ecosystem basis, as well as from social media studies (Aryffin et al., 2021; Ahmad et al., 2022). The Pre-MOVE Forum also discussed digital data as an article of trade, e.g., open sales of crash evidence on social media.
- Rethink the implementation of e-Call (Ilyas, 2018; Chan, 2018) – for example, a new approach via aftermarket devices such as SIM-enable (or eSIM) dashcams. Also referred to as Automatic Collision Notification (ACN) (Donnelly et al., 2001).
- Relook at the implementation of tracking (GPS) by APAD among buses and HGVs (APAD, 2022).
- Conduct regular assessments on ITS implementation in the country – refer to Appendix I (MOW, 2019).
- Black box and digital data concerns are more obvious in AV scenarios; thus, this is another big challenge for modern cars, especially in the local context (Bonnefon et al., 2016; Kassim et al.,

2019; Utesch et al., 2020; Karjanto et al., 2021). More assessments regarding available autonomous functions such as Adaptive Cruise Control (ACC) will help in giving early indications (Chan, 2021; Li et al., 2021).

- Quite recently many parking lots have been installed with the Automatic Number Plate Recognition (ANPR) system, which requires studies about data integrity concerns (Jawi & Isa, 2017). This may not be relevant to the discussion (car produces digital data) because it works passively from a car perspective, but users are somewhat similarly exposed to Car2X/V2X features and this is important in the near future – e.g., wireless payment from a car, ANPR with e-wallet facility, etc. (Roy et al., 2016; Abd Rahman et al., 2022).
- Also not in the discussion context is to assist enforcement agencies with the usage of devices such as body cam and helmet cam, as well as digital data management.

Regional level:

- Data generation among ASEAN countries – there is a possibility that more ASEAN data can be collected, especially in a voluntary scenario. In order to better shape regional demand (automotive offerings) and other road safety countermeasures, data from the “Big 5” countries (Indonesia, the Philippines, Thailand, Vietnam, and Malaysia) is very crucial (Jawi & Kassim, 2013; Abidin et al., 2021).
- To analyze the effects of the latest vehicle systems on inter-country travel, e.g., Vehicle Entry Permit (VEP) and Road Charge (RC). Malaysia provides land travel to Singapore (via bridge), Thailand, Brunei, and Indonesia.
- To participate and organize regional-based meetings and conferences on the subject of interest, including government-to-government (G2G) ASEAN level – ASEAN Cybersecurity Cooperation Strategy (ASEAN, n.d.).

International level:

- To participate in and organize international meetings and conferences including global G2G platforms.
- Collaboration with INTERPOL (Automotive Cyber Threat and Vehicle Forensics) and Asian Forensic Sciences Network (AFSN) (Bates, 2019; Ross & Neuteboom, 2021).
- Involvement in creating global standards is very important and will benefit both industries and users (Kopencova & Rak, 2020) – specific studies with Malaysian/ASEAN data are therefore necessary.

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APPENDIX I - ITS Sectors and User Services from Malaysian ITS Blueprint: 2019-2023 (MOW, 2019)

ITS Sectors	User-Services		
ITS Sector No.1: Advanced Traffic Management Systems	1	1.1	Urban Traffic Control
	2	1.2	Incident Detection and Management
	3	1.3	Travel Demand Management
	4	1.4	Environmental Conditions Management
	5	1.5	Operations and Maintenance
	6	1.6	Non-Vehicular Road User Safety
	7	1.7	Multi-Modal Junction Safety and Control
ITS Sector No.2: Safety Systems	8	2.1	Improved Accident Data Collection
	9	2.2	Automated Dynamic Warning and Enforcement
ITS Sector No.3: Advanced Public Transport Systems	10	3.1	Public Transport Operations Management
	11	3.2	Public Transport En-Route Information
	12	3.3	Demand Responsive Public Transport
	13	3.4	Public Travel Security
ITS Sector No.4: Advanced Traveller Information Systems	14	4.1	Pre-Trip Traveller Information
	15	4.2	Route Guidance and Navigation
	16	4.3	Ride Matching and Reservation
	17	4.4	Traveller Services and Reservations
ITS Sector No.5: Electronic Payment Systems	18	5.1	Electronic Payment Services
ITS Sector No.6: Commercial Vehicle Operations Systems	19	6.1	Commercial Fleet Management
	20	6.2	Commercial Freight Management
	21	6.3	Commercial Vehicle Electronic Clearance
	22	6.4	Automated Roadside Safety Inspection
	23	6.5	On-board Safety Monitoring
	24	6.6	Commercial Vehicle Administrative Processes
ITS Sector No.7: Advanced Vehicle Control Systems	25	7.1	Vehicle-Based Collision Avoidance
	26	7.2	Infrastructure-Based Collision Avoidance
	27	7.3	Sensor-Based Driving Safety Enhancement
	28	7.4	Safety Readiness
	29	7.5	Pre-Collision Restraint Deployment
	30	7.6	Automated Vehicle Operation
ITS Sector No.8: Emergency Management Systems	31	8.1	Emergency Notification and Personal Security
	32	8.2	Hazardous Material Planning and Incident Response
	33	8.3	Disaster Response and Management
	34	8.4	Emergency Vehicle Management
ITS Sector No.9: Information Warehousing Systems	35	9.1	Weather and Environmental Data Management
	36	9.2	Archived Data Management