# CONCEPTUAL AND PROTOTYPE DEVELOPMENT OF DRIVING CYCLE TRACKING DEVICE FOR ROUTE-TO-WORK DRIVING CYCLE IN KUALA TERENGGANU CITY, MALAYSIA

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ABSTRACT
Driving cycle is commonly known as the relationship between speed and time of a vehicle. Major application of driving cycle is to aid vehicle manufacturers, traffic engineers and environment engineers regarding pollution and emission studies. To develop an accurate driving cycle, information on real-time based driving behaviour is important. This paper concentrates on three major phases: to model a conceptual design of driving cycle tracking device (DC-TRAD) for route-to-work driving cycle in Kuala Terengganu city (RTW DC in KT city) in MATLAB/Simulink environment; to develop a prototype of DC-TRAD for RTW DC in KT city; and to analyse the obtained results of conceptual design and prototype for DC-TRAD using RTW DC in KT city. This research validates the conceptual model and prototype of DC-TRAD on RTW DC in KT city and the results obtained in this research supports the idea of importance of driving cycle.
*Keywords: DC-TRAD, driving cycle, hybrid electric vehicle, Internet of Things, route-to-work, Simulink, fuel economy, emissions*

## 1 INTRODUCTION

Global warming and environment deterioration are faced globally in which the main root cause of these issues is the drastic rise on vehicle numbers on roads. The efficiency of the internal burning of a vehicle is in satisfactory condition yet it is often operated in lower load in which it reduces the efficiency of the motor combustion [1]. This statement is also supported in Afroz et al. [2] which states 70% to 75% of contribution to air pollution is by land transportation. According to Achour and Olabi [3], one of the main causes of climate changes due to greenhouse gasses emission is the excess release of carbon from the vehicle exhaust. The recent development in the study of environment and vehicle emission had been a cause for the establishment of application of driving cycle. A few challenges are often experienced by engineers in the process of driving cycle development of a chosen route; method of data collection as the cycle varies for every selected routes.

According to Aziz [4], Malaysia is at its initial stage of driving cycle development. In general, there are three modes of driving which is idle, low, and medium speed. There are a few established driving cycles such as worldwide harmonized light vehicle test cycle (WLTC), new European drive cycle (NEDC), federal test procedure (FTP). It is not a good practice to conduct research and studies on Malaysian routes by using other countries' driving cycle as the road condition and driving behavior of individuals would not be the same. According to Nicolas [5], driving cycles are often represented in a speed–time relation curve. Driving cycles are also used to access fuel consumption and pollutant agent analysis.

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Driving cycle tracking device (DC-TRAD) had been developed in which it collects parameters required to develop driving cycles which is speed and time and store instantly in Google spreadsheet as the Internet of Things (IoT) big data management platform [6]. However, Google spreadsheet had stopped supporting IoT application effective December 2019 [7]. Therefore, this research is an initiative to expand the research of DC-TRAD and to improvise IoT big data management platform by using MySQL database management which is in line with industrial revolution 4.0 (IR4.0). In general, the cost to develop a complete device is relatively high in which the device must be installed in the vehicle through on-board diagnostic (OBD) port of the vehicle. As an initiative to reduce the cost of production, a conceptual model of DC-TRAD is developed and designed using MATLAB/Simulink environment. The importance of simulation in industry mainly automotive is supported by Llopis-Albert et al. [8] in which states that the efficiency of the production can be improved with simulation. MATLAB/Simulink is widely used in automotive industries for simulation purpose since it has powertrain, vehicle dynamics, automated driving toolbox and model-based calibration toolbox block sets. The conceptual model of DC-TRAD works closely by mean of integration, derivation, and interpolation to retrieve information from speed. In addition, a comparative study was also conducted to compare the results of DC-TRAD prototype and conceptual model on RTW DC in KT city. As a step towards realization of sustainable goal development (SDG), DC-TRAD is designed to provide information regarding ways to correct driving styles if it is not up to the standard of a proper driving behavior. Lastly, to emphasize the importance of driving cycle in automotive industry, a model of electric vehicle (EV) had been designed and the collected data of RTW DC in KT city was simulated in the model to analyze fuel consumption, electric consumption, and battery specifications.

## 2 METHODOLOGY

Five methods involved in this research are discussed.

### 2.1 Modelling of DC-TRAD in MATLAB/Simulink

Indefinite integrals are commonly used to solve problems related to motion with respective to time. The derivation of instantaneous acceleration and indefinite integral of speed gives distance [9]. Speed derivation formula is given by eqn (1).

$$\frac{d}{dx}(v(t)) = a(t). \tag{1}$$

Integration is the reverse of derivation. Integration was used to obtain distance travelled from speed signal. Formula of integration is given by eqn (2).

$$\int v(t)\,dt = s(t). \tag{2}$$

### 2.2 Validation of conceptual model

Upon construction of conceptual modelling of DC-TRAD in MATLAB/Simulink, the model was validated with two established driving cycles which are Kuala Terengganu BasKITE and highway fuel economy test (HWFET). Ten parameters were chosen for analysis which is time taken, distance travelled, average speed, average running speed, average acceleration, average deceleration, acceleration percentage, deceleration percentage, idling percentage and cruising percentage

### 2.3 DC-TRAD prototype development

From the previous research of DC-TRAD, two components had been upgraded which is GPS sensing technique and IoT application. Taking accuracy of data capturing into concern, U-BLOX plays the role to capture speed information and has higher accuracy. To add to that, IoT is a new approach that has drastically amended the way of data storing and data management in which lifestyles can be upgraded technically [10]. In this research, a new cloud interface was used which is phpMyAdmin; a partner platform of MySQL database management with the aid of XAMPP webserver. Steps of configuration are as follows:
**STEP 1:** phpMyAdmin setup file was downloaded and run for standard installation at https://www.phpmyadmin.net/downloads/.
**STEP 2:** XAMPP webserver was downloaded for Apache and MySQL initialization at https://www.apachefriends.org/download.html.
**STEP 3:** Upon installation and initialization, XAMPP webserver was initiated and Apache and MySQL were started in accordance.
**STEP 4:** Localhost interface was started at http://localhost/phpmyadmin**.** By default, the Username is "root" with password space left blank. Upon successful login, it is highly recommended to change password to protect database. A new database was created with the name "gpsdata" and data named "gps_table". Database preplan is required in which name of parameters, type of data and length of data have to be setup at the early stage to ensure data key in is done in a proper manner. In this research, column named time, latitude, longitude, speed and time was initialized to data type "double". A SQL data interface was also created for data communication between GPS with phpMyAdmin.
**STEP 5:** A webpage was created using MySQL and PHP code which can be logged in anywhere by using localhost internet protocol (IP) address. Please take note that several security options must be enabled to ensure data privacy and protection plan. As per the name of the device defines, together with this, a separate Webpage was also created in which the collected speed–time relation curve can be viewed instantly on the webpage with the link provided. Webpage viewing was done with the combination of JAVA and PHP coding.

### 2.4 DC-TRAD analysis

Five routes of RTW DC in KT city were chosen to be used in this research [11]. Fig. 1 shows the five selected routes which are Route A, Route B, Route C, Route D and Route E respectively. DC-TRAD prototype was validated and verified by comparing the parameters with driving cycle generated through SpeedView application. In accordance, the data collected through DC-TRAD prototype was simulated in DC-TRAD conceptual design to analyze the chosen ten parameters between prototype and simulated DC-TRAD.

### 2.5 Application in EV technology by using RTW DC for KT city

Driving cycles are often used by automotive sectors to analyze efficiency of vehicles for instance, EV. In this research, a model of EV was designed in MATLAB/Simulink in which data collected on RTW DC in KT city by using DC-TRAD was simulated. Data collected on five routes of RTW DC for KT city using DC-TRAD were uploaded into signal builder of the model and it acted as the required data whereas the simulated driving cycle acted as the acquired driving cycle. Eight parameters were chosen for analysis which is average speed, average running speed, average acceleration, average deceleration, percentage of acceleration and deceleration distance travelled, and time taken to complete the trip.

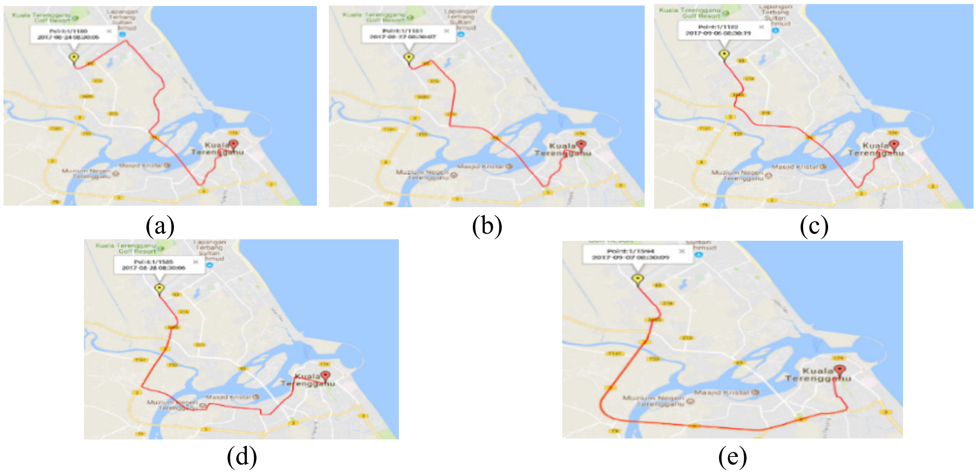



Figure 1: (a) Route A; (b) Route B; (c) Route C; (d) Route D; and (e) Route E.

Besides, battery simulation parameters were also analyzed; battery SOC, battery parameters (voltage, current, power), kWh charges and fuel charges incurred in Ringgit Malaysia (RM) for the driving cycle route selected.

## 3 RESULTS AND DISCUSSION

### 3.1 Modelling of DC-TRAD in MATLAB/Simulink

Speed data was used in which distance travelled was calculated by integrating speed and the data of acceleration was obtained through the first derivative of speed. Fig. 2 shows the conceptual model of DC-TRAD. Eqns (3) and (4) show the interpolation of distance and velocity respectively. A digital clock was integrated to ensure time stamping and sampling

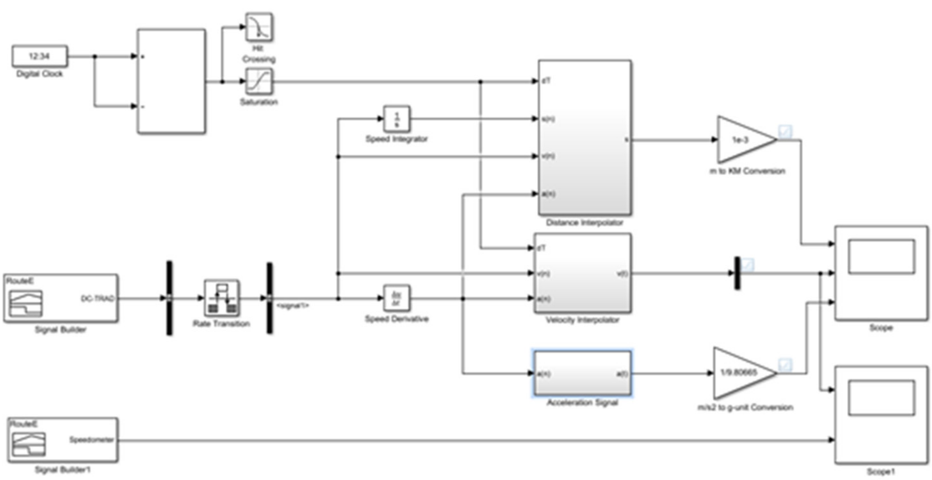



Figure 2: DC-TRAD conceptual model.

time of one second. A rate transition block was also integrated into each output of the model to ensure the efficiency of data transfer from one rate to a different rated block.

$$(n) + \frac{a(n)}{2} dT^2 + v(n)dT = s. \quad (3)$$

$$a(n)dT + v(n) = v(t). \quad (4)$$

### 3.2 Validation of conceptual model

The model was then verified with two established driving cycles which are Kuala Terengganu BasKITE and HWFET. Raw data points from each driving cycles were simulated in the model and connected to scope to identify signal losses throughout the simulation and as a procedure to verify and validate the model. Tables 1 and 2 show the tabulated result for Kuala Terengganu BasKITE and HWFET respectively. All the data points compared has an error of below 5%. To conclude, there is no signal losses during simulation process and thus the conceptual model of DC-TRAD is verified and validated.

Table 1: Data analysis for Kuala Terengganu BasKITE driving cycle.

| Items | Established driving cycle | Conceptual DC-TRAD | Error (%) |
|---|---|---|---|
| Time (s) | 2617.0000000 | 2617.0000000 | 0.0000000 |
| Distance (km) | 15.6252157 | 15.6300000 | 0.0306191 |
| Avg speed (m/s) | 5.9683790 | 5.9680000 | 0.0063501 |
| Avg run speed (m/s) | 6.9817760 | 6.9820000 | 0.0032084 |
| Avg acc ($m/s^2$) | 0.4476390 | 0.4458760 | 0.3938441 |
| Avg dec ($m/s^2$) | 0.4948900 | 0.4875236 | 1.4884924 |
| Acc (%) | 45.6073340 | 45.5214586 | 0.1882930 |
| Dec (%) | 41.2528650 | 41.2415620 | 0.0273993 |
| Idling (%) | 13.1016040 | 13.1900000 | 0.6746960 |
| Cruising (%) | 0.0381970 | 0.0375896 | 1.5901772 |

Table 2: Data analysis for HWFET driving cycle.

| Items | Established driving cycle | Conceptual DC-TRAD | Error (%) |
|---|---|---|---|
| Time (s) | 765.0000000 | 765.0000000 | 0.0000000 |
| Distance (km) | 16.5100787 | 16.5100000 | 0.0004768 |
| Avg speed (m/s) | 21.5536280 | 21.5500000 | 0.0168324 |
| Avg run speed (m/s) | 21.7237880 | 21.6987452 | 0.1152782 |
| Avg acc ($m/s^2$) | 0.1942000 | 0.1945620 | 0.1864058 |
| Avg dec ($m/s^2$) | 0.1942000 | 0.1939900 | 0.1081359 |
| Acc (%) | 44.1253260 | 44.1354120 | 0.0228576 |
| Dec (%) | 38.7728460 | 38.7487950 | 0.0620305 |
| Idling (%) | 0.6527420 | 0.6712540 | 2.8360363 |
| Cruising (%) | 16.4490860 | 16.4458521 | 0.0196601 |

### 3.3 DC-TRAD prototype development

After setting up database for data collection and management, the prototype was connected as per Fig. 3.

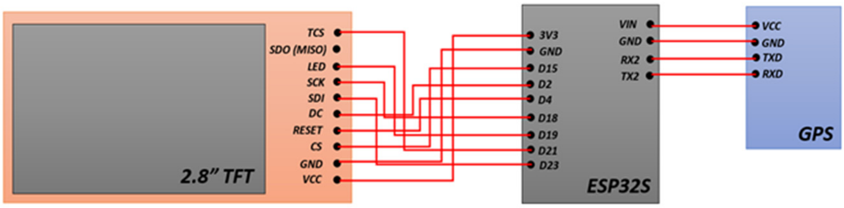


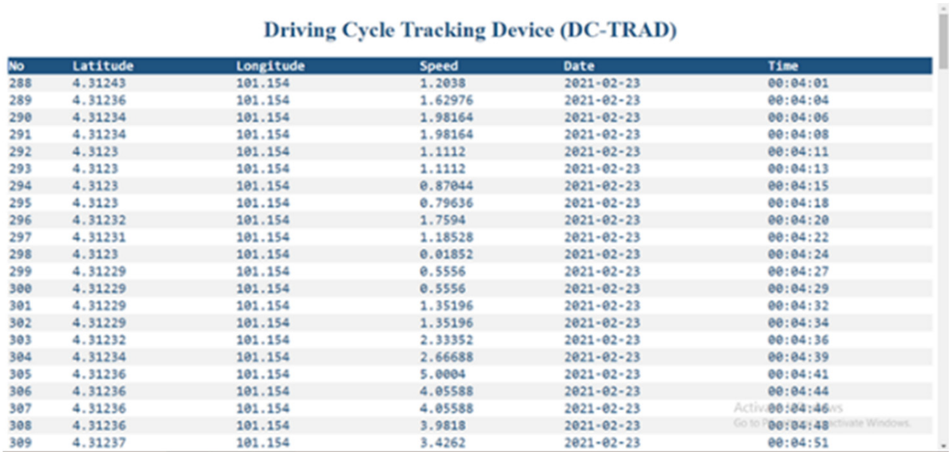

Figure 3: Connection of DC-TRAD.

DC-TRAD works closely with U-BLOX GPS sensor as it provides a good platform to retrieve information related to location and speed. Data retrieved by GPS sensor was sent to data processing unit of ESP32S in which it analyses the data collected and processes the data according to how it is programmed. A 2.8" Thin Film Transistor (TFT) screen was also used to display the retrieved data which will be refreshed automatically for every one second. The collected data was sent and updated into phpMyAdmin database instantly and webpage which was created in STEP 5 of phpMyAdmin database setup was updated instantly. The collected speed data points were also plotted instantly on the speed–time webpage coded for instant monitoring. A "successful" key was included for data posting indication and upon every successful data update into phpMyAdmin database, "successful" key shall be displayed on the screen. In phpMyAdmin, a webpage entitled Driving Cycle Tracking Device (DC-TRAD) was created with six respective columns which are number, latitude, longitude, speed, date, and time to store collected parameters. The webpage was programmed to be updated for every one second for new incoming data points. Since the webpage was constructed using IP Address, the link to access the webpage is given in general which is http://example-domain.com/ViewGpsVal.php and speed–time relation curve can be viewed instantly on http://example-domain.com/SpeedTimeView.php in which "example-domain.com" is to be replaced with laptop IP Address. Fig. 4 shows the constructed prototype of DC-TRAD. Fig. 5 shows the webpage interface created for data updating and Fig. 6 shows the speed–time relation curve webpage.

## 3.4 DC-TRAD analysis

Data collection was carried out to verify and validate DC-TRAD prototype. SpeedView application was chosen to be used as reference which was developed by Code Sector. Start and end point of the routes were set as the constant variable in which the routes start from Kampung Wakaf Tembesu and end at Wisma Persekutuan Kuala Terengganu. Tables 3–7 show the results obtained for all the chosen parameters.


Figure 4: DC-TRAD prototype.



Driving Cycle Tracking Device (DC-TRAD)

| No | Latitude | Longitude | Speed | Date | Time |
|---|---|---|---|---|---|
| 288 | 4.31243 | 101.154 | 1.2038 | 2021-02-23 | 00:04:01 |
| 289 | 4.31236 | 101.154 | 1.62976 | 2021-02-23 | 00:04:04 |
| 290 | 4.31234 | 101.154 | 1.98164 | 2021-02-23 | 00:04:06 |
| 291 | 4.31234 | 101.154 | 1.98164 | 2021-02-23 | 00:04:08 |
| 292 | 4.3123 | 101.154 | 1.1112 | 2021-02-23 | 00:04:11 |
| 293 | 4.3123 | 101.154 | 1.1112 | 2021-02-23 | 00:04:13 |
| 294 | 4.3123 | 101.154 | 0.87044 | 2021-02-23 | 00:04:15 |
| 295 | 4.3123 | 101.154 | 0.79636 | 2021-02-23 | 00:04:18 |
| 296 | 4.31232 | 101.154 | 1.7594 | 2021-02-23 | 00:04:20 |
| 297 | 4.31231 | 101.154 | 1.18528 | 2021-02-23 | 00:04:22 |
| 298 | 4.3123 | 101.154 | 0.01852 | 2021-02-23 | 00:04:24 |
| 299 | 4.31229 | 101.154 | 0.5556 | 2021-02-23 | 00:04:27 |
| 300 | 4.31229 | 101.154 | 0.5556 | 2021-02-23 | 00:04:29 |
| 301 | 4.31229 | 101.154 | 1.35196 | 2021-02-23 | 00:04:32 |
| 302 | 4.31229 | 101.154 | 1.35196 | 2021-02-23 | 00:04:34 |
| 303 | 4.31232 | 101.154 | 2.33352 | 2021-02-23 | 00:04:36 |
| 304 | 4.31234 | 101.154 | 2.66688 | 2021-02-23 | 00:04:39 |
| 305 | 4.31236 | 101.154 | 5.0004 | 2021-02-23 | 00:04:41 |
| 306 | 4.31236 | 101.154 | 4.05588 | 2021-02-23 | 00:04:44 |
| 307 | 4.31236 | 101.154 | 4.05588 | 2021-02-23 | 00:04:46 |
| 308 | 4.31236 | 101.154 | 3.9818 | 2021-02-23 | 00:04:48 |
| 309 | 4.31237 | 101.154 | 3.4262 | 2021-02-23 | 00:04:51 |

Figure 5: DC-TRAD webpage.

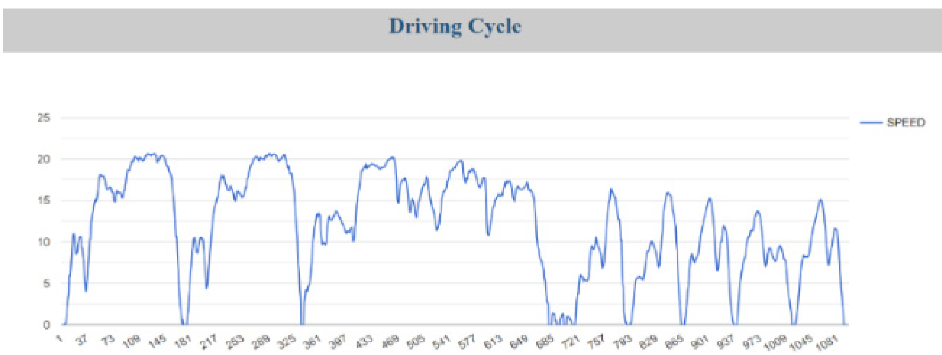



Figure 6: Driving cycle webpage.

Table 3: Parameters of Route A.

| Items | SpeedView | DCTRAD prototype | Simulation | Error (%) (SpeedView and prototype) | Error (%) (prototype and simulation) |
|---|---|---|---|---|---|
| Time (s) | 670.0000 | 670.0000 | 670.0000 | 0.0000 | 0.0000 |
| Distance (km) | 13.5000 | 13.3200 | 13.3210 | 1.3333 | 0.0075 |
| Avg speed (m/s) | 18.0744 | 18.6760 | 18.5532 | 3.3285 | 0.6573 |
| Avg run speed (m/s) | 18.9810 | 18.7882 | 18.8861 | 1.0158 | 0.5214 |
| Avg acc ($m/s^2$) | 0.9787 | 1.0100 | 0.9679 | 3.1981 | 4.1641 |
| Avg dec ($m/s^2$) | 1.1226 | 1.1430 | 1.1133 | 1.8172 | 2.6065 |
| Acc (%) | 46.2700 | 46.2700 | 46.6700 | 0.0000 | 0.8645 |
| Dec (%) | 40.3000 | 40.9000 | 40.4157 | 1.4888 | 1.1841 |
| Idle (%) | 4.6300 | 0.7500 | 0.7739 | 83.8013 | 3.1867 |
| Cruise (%) | 8.8100 | 12.0900 | 12.1975 | 37.2304 | 0.8892 |

Table 4: Parameters of Route B.

| Items | SpeedView | DCTRAD prototype | Simulation | Error (%) (SpeedView and prototype) | Error (%) (prototype and simulation) |
|---|---|---|---|---|---|
| Time (s) | 826.0000 | 826.0000 | 826.0000 | 0.0000 | 0.0000 |
| Distance (km) | 15.1200 | 14.9600 | 15.1200 | 1.0582 | 2.8743 |
| Avg speed (m/s) | 11.9998 | 12.1891 | 11.9998 | 1.5775 | 1.2487 |
| Avg run speed (m/s) | 12.9178 | 13.0982 | 12.9178 | 1.3965 | 1.1075 |
| Avg acc ($m/s^2$) | 0.9761 | 0.9896 | 0.9761 | 1.3831 | 1.5223 |
| Avg dec ($m/s^2$) | 1.0509 | 1.0621 | 1.0509 | 1.0658 | 2.7821 |
| Acc (%) | 42.2500 | 42.3700 | 42.2500 | 0.2840 | 0.6844 |
| Dec (%) | 39.3500 | 39.5900 | 39.3500 | 0.6099 | 0.8790 |
| Idle (%) | 6.3000 | 2.0600 | 6.3000 | 67.3016 | 0.8204 |
| Cruise (%) | 12.1100 | 15.9800 | 12.1100 | 31.9571 | 0.1959 |

Table 5: Parameters of Route C.

| Items | SpeedView | DCTRAD prototype | Simulation | Error (%) (SpeedView and prototype) | Error (%) (prototype and simulation) |
|---|---|---|---|---|---|
| Time (s) | 788.0000 | 788.0000 | 788.0000 | 0.0000 | 0.0000 |
| Distance (km) | 8.3300 | 8.2300 | 8.2600 | 1.2005 | 0.3645 |
| Avg speed (m/s) | 11.9577 | 12.1741 | 11.9975 | 1.8097 | 1.4506 |
| Avg run speed (m/s) | 13.1601 | 12.4911 | 12.9563 | 5.0835 | 3.7240 |
| Avg acc ($m/s^2$) | 0.8301 | 0.8423 | 0.8534 | 1.4697 | 1.3209 |
| Avg dec ($m/s^2$) | 0.9995 | 1.0147 | 1.0241 | 1.5208 | 0.9243 |
| Acc (%) | 43.9100 | 43.9100 | 41.7655 | 0.0000 | 4.8839 |
| Dec (%) | 36.4200 | 36.4200 | 38.2056 | 0.0000 | –4.9028 |
| Idle (%) | 10.4100 | 4.0600 | 4.0468 | 60.9990 | 0.3251 |
| Cruise (%) | 9.2600 | 15.6100 | 15.9876 | –68.5745 | –2.4190 |

Table 6: Parameters of Route D.

| Items | SpeedView | DCTRAD prototype | Simulation | Error (%) (SpeedView and prototype) | Error (%) (prototype and simulation) |
|---|---|---|---|---|---|
| Time (s) | 737.0000 | 737.0000 | 737.0000 | 0.0000 | 0.0000 |
| Distance (km) | 15.0100 | 14.9000 | 15.2100 | 0.7328 | 2.0805 |
| Avg speed (m/s) | 17.5458 | 17.7778 | 17.4365 | 1.3223 | 1.9196 |
| Avg run speed (m/s) | 17.9601 | 17.8019 | 17.8850 | 0.8808 | 0.4667 |
| Avg acc ($m/s^2$) | 0.5095 | 0.5253 | 0.5131 | 3.1011 | 2.3160 |
| Avg dec ($m/s^2$) | 0.6165 | 0.6528 | 0.6620 | 5.8881 | 1.4160 |
| Acc (%) | 27.2700 | 28.0900 | 28.0541 | 3.0070 | 0.1278 |
| Dec (%) | 23.0200 | 23.2000 | 23.3760 | 0.7819 | 0.7586 |
| Idle (%) | 13.0300 | 10.0400 | 9.8970 | 22.9470 | 1.4243 |
| Cruise (%) | 36.5000 | 38.6700 | 38.6962 | 5.9452 | 0.0678 |

Table 7: Parameters of Route E.

| Items | SpeedView | DCTRAD prototype | Simulation | Error (%) (SpeedView and prototype) | Error (%) (prototype and simulation) |
|---|---|---|---|---|---|
| Time (s) | 898.0000 | 898.0000 | 898.0000 | 0.0000 | 0.0000 |
| Distance (km) | 13.8000 | 13.2900 | 13.3100 | 3.6957 | 0.1505 |
| Avg speed (m/s) | 13.1658 | 13.1204 | 13.2210 | 0.3448 | 0.7665 |
| Avg run speed (m/s) | 13.5273 | 13.1497 | 13.1532 | 2.7914 | 0.0265 |
| Avg acc (m/s$^2$) | 0.6855 | 0.6815 | 0.6746 | 0.5835 | 1.0095 |
| Avg dec (m/s$^2$) | 0.7974 | 0.7999 | 0.8130 | 0.3135 | 1.6387 |
| Acc (%) | 43.4300 | 43.4300 | 43.4120 | 0.0000 | 0.0414 |
| Dec (%) | 37.4200 | 37.0800 | 37.1142 | 0.9086 | 0.0922 |
| Idle (%) | 3.2300 | 1.1100 | 1.1076 | 65.6347 | 0.2162 |
| Cruise (%) | 15.9200 | 18.3700 | 18.4432 | 15.3894 | 0.3985 |

A typical mobile phone GPS is accurate up to 4.9 m radius [12] whereas U-BLOX GPS sensor has an accuracy of 1 m radius [13]. The accuracy of U-BLOX GPS sensor can be seen during braking effect in which the speed of vehicle was detected and captured when the speed is at non-zero state. Due to this, the cruise and idle percentage shoots high by approximately 1.5 times higher.

According to Ribbens et al. [14], in a cruise control mode, brakes are automatically applied to maintain the speed of the vehicle motor. The variance of cruising and idling percentage plays an important role in driving cycle development as it decides the number of micro trips between each data points. With an accurate driving cycle development, global warming and climate change issues which are discussed globally can be addressed in which emission rates of the chosen route can be analysed in a more accurate manner.

3.5 Application in EV technology by using RTW DC for KT city

Fig. 7 shows the EV model in MATLAB/Simulink. Respective calculations of rotations per minute (RPM), average speed, average running speed, average acceleration, average deceleration, acceleration percentage, deceleration percentage, idle percentage and cruise percentage were executed in the calculation block of each route of RTW DC in KT city. Data

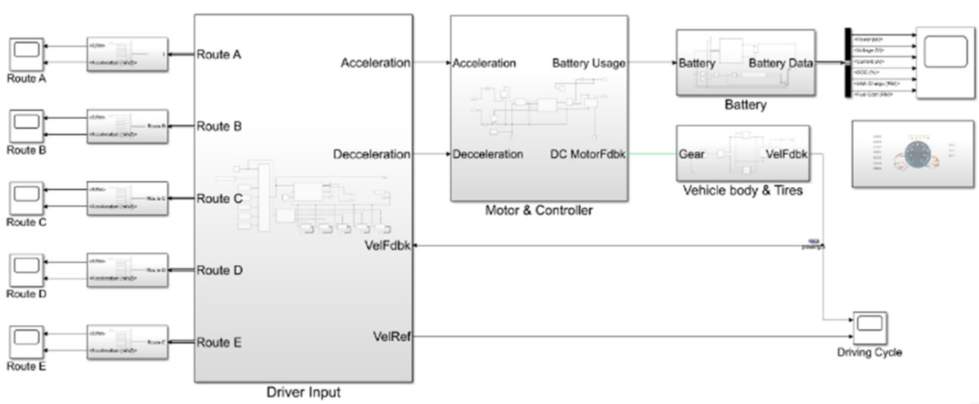



Figure 7: EV model.

collected on RTW DC in KT city by using DC-TRAD were simulated in the constructed EV model to validate the model and in accordance, kWh, and RM costings on RTW DC in KT city were analysed. Fig. 8 shows the comparison of DC-TRAD and EV simulation driving cycle for all routes.

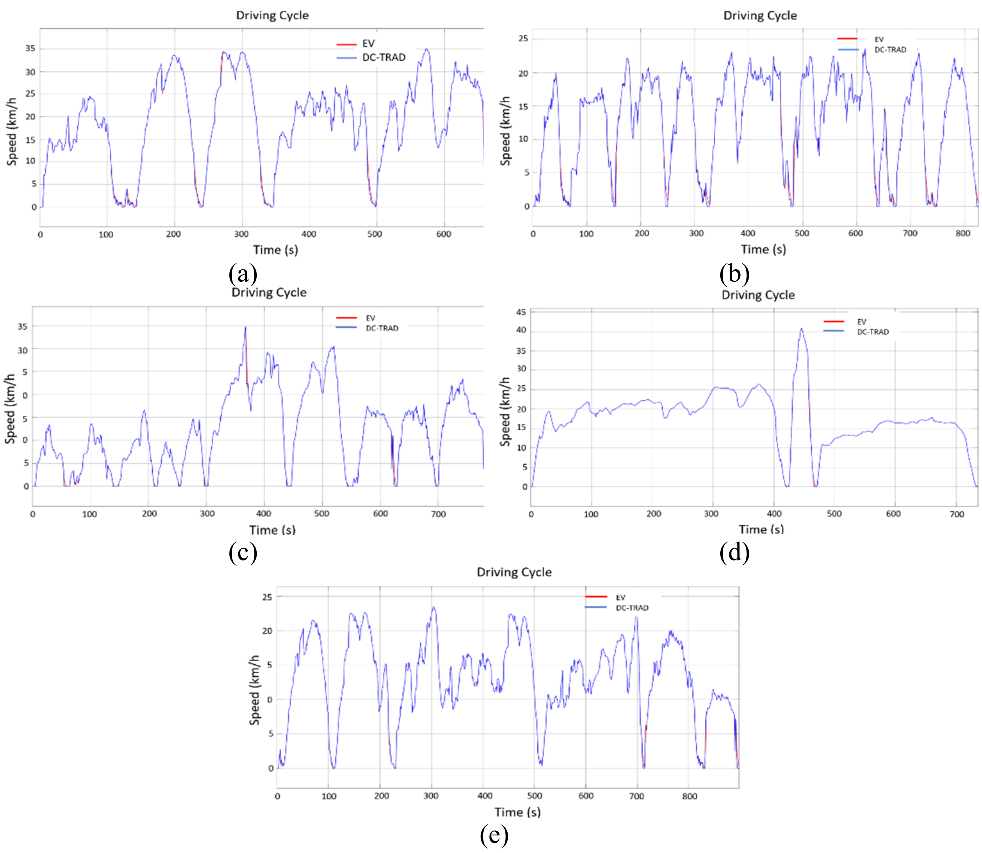



Figure 8: (a) Route A; (b) Route B; (c) Route C; (d) Route D; and (e) Route E.

As per simulation of Route A, B, C, D and E driving cycle, 95% of the acquired data are within range in which it is below 5% of error. Looking in detail at each driving cycle, the data recorded which is out of range is at the point of deceleration where the required data records zero m/s and acquired data records slightly higher which is recorded in mm/s.

This is due to the inertia force of the vehicle in which inertia is defined as the tendency to remain at zero speed if in a motion until an external force is applied in physics. Together with this, a generic battery model was also integrated to analyze battery specification of the vehicle on the selected five routes. Table 8 shows the battery specification analysis results.

The maximum charging capacity of a battery was set at 350 V with internal resistance of 0.03 Ω to maintain performance of the battery at the nominal operation. This is defined as float voltage in which the battery will be charged above nominal voltage to ensure backup power when it is unused and to make up with the self-discharge of the battery [15]. Therefore,

Table 8: Battery specification analysis.

| Item | Unit | Route A | Route B | Route C | Route D | Route E |
|---|---|---|---|---|---|---|
| Peak power | kW | 240.20 | 308.10 | 297.45 | 213.50 | 302.33 |
| Peak current | A | 780.40 | 910.15 | 960.34 | 708.80 | 970.23 |
| Peak voltage | V | 367.80 | 370.60 | 361.60 | 364.70 | 364.50 |
| Battery SOC | % | 95.00 | 93.67 | 95.22 | 94.02 | 95.00 |
| kWh charge | RM | 1.72 | 2.26 | 1.73 | 2.31 | 1.98 |
| Fuel charge | RM | 3.70 | 4.31 | 3.33 | 4.48 | 4.05 |

a float voltage of 60V was set into generic battery model with overall 10% slip. There were a few major spikes on motor power which lasted for a second for each route which is defined as overloading of motor [16]. In terms of battery SOC, Route B and D used up the maximum amount of battery charge as the distance travelled in respective routes were the longest which is 15.30 km and 15.20 km respectively whereas Route C used up the least amount of battery in which upon simulation completion, there were 95.22% of battery SOC left with the least distance travelled which is 8.33 km. The kinetic energy which is produced during braking is stored back into the battery of the vehicle in which it can be reused for acceleration and deceleration commands and for other vehicle accessories which is also known as regenerative braking. Battery charge which is stored in the battery upon braking effects is relatively small which is within the range of 0.2 V–0.7 V. Besides, the costings for each route were also calculated and analysed in accordance. Overall, the cost of travelling in all routes are two times cheaper by using EV compared to fuel powered vehicles.

## 4 CONCLUSION

To summarize, a conceptual design of DC-TRAD had been designed in MATLAB/Simulink and validated with established driving cycles (Kuala Terengganu BusKITE and HWFET) in which raw data of driving cycle was uploaded into the model to be simulated and parameters such as acceleration and total distance travelled will be drawn out through the simulation and found errors to be below 5%. Secondly, a conceptual design of an EV is modelled in MATLAB/Simulink and data collected on RTW DC in KT city using DC-TRAD was simulated in the model. Various parameters were analysed such as time travelled, distance travelled, average speed, average running speed, average acceleration, average deceleration, acceleration percentage, deceleration percentage, idling percentage, cruising percentage, battery voltage, battery current, battery power, battery SOC, kWh cost and fuel cost for all the selected routes of RTW DC in KT city. Most of the parameters are within acceptable range which is below 5% except battery current and power due to absence of relative resistance to limit the amount of current flowing into the electric motor and overload protection relay for the electric motor as a safety measure. By comparing the cost of travelling for all the routes, EV is proven to be more efficient where the cost of travelling is comparatively two times lower compared to the cost of fuel. By implementing DC-TRAD data collection in the process of driving cycle development, it is therefore proven it is an efficient way of data collecting strategy to ensure accuracy of driving cycle. To add to that, it is also proven, with an accurate driving cycle, analysis such as fuel consumption and emission can also be improved which contributes to the success of SDG goals' objectives.

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