Full EV vehicle model for digital authentication through virtual testing

- Comprehensive CO2 reduction and new manufacturing methods -

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ABSTRACT: Until now, physical testing and certification have been accepted because of the reassurance that it is performed on actual products. However, the test conditions that must be satisfied by physical testing and certification have become increasingly diverse, and it is becoming more difficult to meet these conditions with physical testing. It is thought that certification by simulation with guaranteed equivalent performance can guarantee more realistic values. The authors have started a demonstration test to verify the equivalence of the EV vehicle model developed by the authors to actual measurements and the certification mechanism using the model.

KEY WORDS: Digital Twin, Virtual Test, Digital Authentication and Certification, VHDL-AMS, IEC61691-6

1. INTRODUCTION

Due to its overwhelming convenience, digital data distribution in cyberspace is becoming the backbone of industry, and its reliability is now greater than that of physical objects. At the same time, in manufacturing, certification through physical testing is reaching its limits due to lack of reproducibility and the diversity of conditions. In this paper, we introduce certification through virtual testing (Fig. 1), and the development of a full-vehicle model of an EV that can be used for comprehensive CO2 reduction and vehicle performance development. This article also introduces the trend toward digital certification and the mechanism aimed at for cloud-based certification with guaranteed security.

Fig.1 An Image of Virtual testing using Digital Twin

Until now, physical testing and certification have been accepted because they give people a sense of security. On the other hand, the conditions and methods for evaluation of physical testing have become more diverse, and there are cases where certification is not appropriate to the actual situation due to the capabilities of the evaluation equipment (time, labor, cost, etc.), and it is more reasonable to certify using simulations with digital twin technology (reducing verification time, evaluation labor, and verification costs), and it is thought that more accurate certification results can be obtained. In addition, physical testing and certification leaves room for fraud in the handling of the tasks, and fraud has been committed many times in the past. With recent advances in digital technology and its security technology, it is thought that the risk of fraud can be significantly reduced by completing testing and certification in an environment such as the cloud.

2. Surrounding Environment

Considering the surrounding environment, reducing CO2 emissions due to global warming has become a major issue that the world must address. Figure 2 shows the composition ratio of electricity generation by power source in major countries. Electricity is the foundation that supports industry, and in Japan, about 70% of electricity generation is derived from fossil fuels. EVs that run on this electricity and the factories that manufacture them also emit CO2 due to this composition ratio of electricity, so there is a risk that choosing an EV for the environment may have the opposite effect due to environmental and design requirements. In this initiative, we will use the entire EV vehicle model as a tool to visualize and reduce CO_2, and to consider it as a rational and easy alternative to certification.

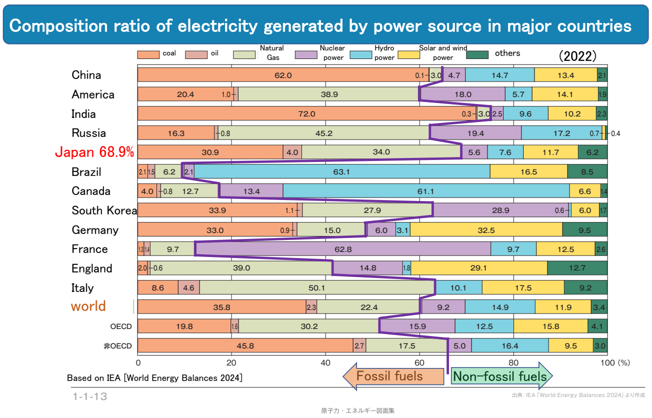


Fig.2 Composition ratio of electricity generated by power source in major countries [1]

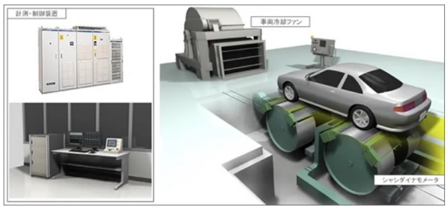
Next, in physical testing, the conditions and methods of evaluation have become more diverse, and there are cases where certification is not meaningful unless it is performed under the original environmental conditions, but due to the capabilities of the evaluation equipment (time, labor, cost, etc.), certification is not based on reality. Therefore, by utilizing a simulation model that has been confirmed to be equivalent to the actual device (digital twin), it is thought that more rational (reduced verification time, reduced evaluation labor, and reduced verification costs) and more accurate and reproducible certification results can be obtained. Here, as an example of an unreasonableness caused by physical testing, the results of the demonstration of the driving distance of an EV are shown. In the case of automobiles, air conditioning is a common feature, but it is extremely difficult to evaluate the environment in which the equipment is operating with good reproducibility, such as the temperature of each part and the effect of heat dissipation due to the wind while driving.

The following shows an environmental chassis dynamometer that simulates the environments of sunlight (Figure 6a) and cold regions (Figure 6b). In terms of sunlight, the luminous intensity is the same regardless of position, and while the sun is parallel light, the light bulb is spherical light whose luminous intensity changes depending on the position. In addition, the wavelength is different from that of actual sunlight, so the temperature inside the vehicle also differs. When evaluating in cold weather, the temperature inside the vehicle varies depending on the performance of the refrigerator and the test site building.

Because certification using this type of test equipment is not practical, the regulatory certification listed as performance in the catalog is an evaluation using a room-temperature chassis dynamometer under room temperature conditions with no heating or cooling, as shown in Fig. 7.

Source: HP of Honda Motor Co., Ltd.
High temperature test
Fig.3a Whole facility heating & strong solar light

Source: Auto Technique Japan Co., Ltd. HP
Fig.3b Low temperature test Whole facility cooling



Source: Meidensha HP
Fig.3c Normal temperature chassis dynamo

Here, what is shown in Fig. 4 is an excerpt of the results of an evaluation of the cruising distance per charge of commercially available EVs conducted by a private evaluation organization in China in 2022 [2]. As can be seen from the figure, when driving with the heating on in an average temperature of -10°C, the driving range was approximately half that of the catalog value. This is the result of not taking into account the air conditioning load at the time of certification, and shows that the air conditioning load (energy), whether heating or cooling, is equivalent to the driving energy. In other words, no matter how accurately an actual vehicle is driven and measured on a room-temperature chassis dynamometer, it is only useful as a reference value.

Therefore, with the aim of making this initiative widely available in the future in a tool-independent manner, we created a simulation model of the entire vehicle using VHDL-AMS (IEC61691-6), which is registered as an international standard

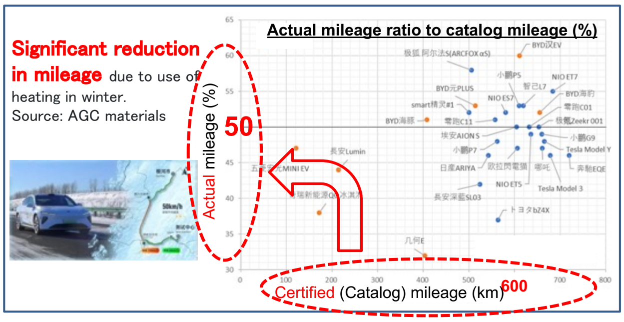


Fig.4 Deviation from catalog value in actual (2)

and has a high degree of completeness as a hardware description language. In the following sections, we will introduce the mechanism for verifying the equivalence of the model with the actual evaluation and for certification.

3. Full-vehicle EV model for digital authentication purposes

As part of METI's FY2020 "Project to Build a Simulation Infrastructure for Accelerating the Development of Next-Generation Vehicles, etc.", we developed an entire EV vehicle model (METI EV model in Fig.5) with the following functions.

Its features include a one-dimensional model that allows for an overall overview and discussion of energy, and reduces the calculation load. The main uses are listed as the functions below. We believe that the accuracy of the digital twin for certification is guaranteed, so we have now begun considering digital certification.

Function: Main applications for consideration.

① Study of improving fuel economy performance during mode driving etc. in vehicle development.

② Study of air conditioning load due to solar radiation etc. to study practical power economy. Study of temperature of each part due to solar radiation etc., and power required for heating and cooling. Study of the effectiveness of off-cycle credit items.

③ Study of the impact of climbing on power economy to study practical power economy. Estimation of power economy and CO2 emissions when driving in urban areas, as well as estimation of high-voltage battery temperature during driving and study of temperature control.

④ Study of vehicle dynamics performance.

⑤ Estimation of battery temperature during quick charging and study of cooling.

⑥ Study of indoor CO2 ventilation using a passenger breath model to study reduction of ventilation loss.

⑦ Study of energy management between home and vehicle.

Block structure, the model is mainly composed of three blocks.

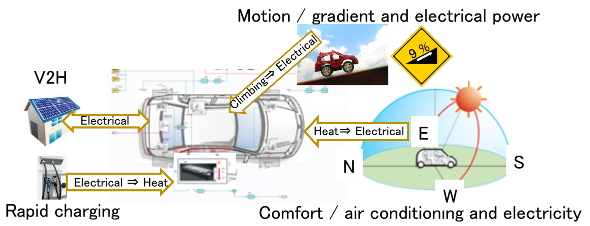


Fig.5 Overview of METI EV model (3)

A) Body & Chassis Block: This block inputs the main vehicle specifications and calculates the vehicle's running resistance and load.

B) Powertrain Block: This block supplies power for the vehicle's powertrain and for heating and cooling the cabin. It has an interface for quick chargers. Energy management with the home is also possible through this block.

C) Cabin Block: The cabin contains an air conditioning model for heating and cooling, an air conditioning load model that simulates heat transfer materials such as windows and door components, and a block that calculates the solar radiation power from the celestial sphere (Fig.5d). By inputting the solar altitude and the angle of the vehicle's light receiving surface, the thermal energy entering the vehicle from each surface can be accurately calculated. Here, the solar constant is set to 1367 W/m2, the transfer coefficient to 0.74, and the solar altitude to 63 degrees. The results will be presented in Section 4. Additionally, with the aim of examining the reduction of ventilation losses, it is also possible to examine the CO2 concentration in the ventilated vehicle interior and electricity consumption using a passenger breath model.

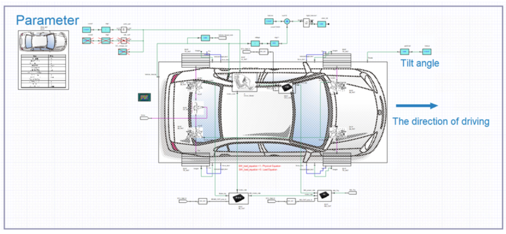


Fig.5a Body & Chassis Block

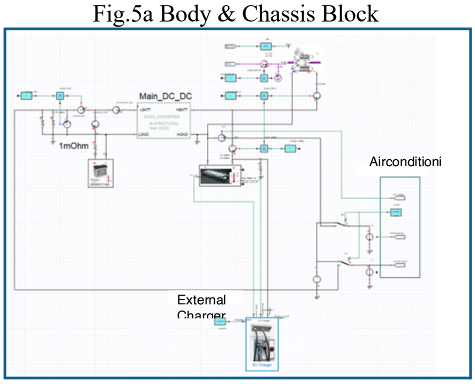


Fig. 5b Powertrain Block

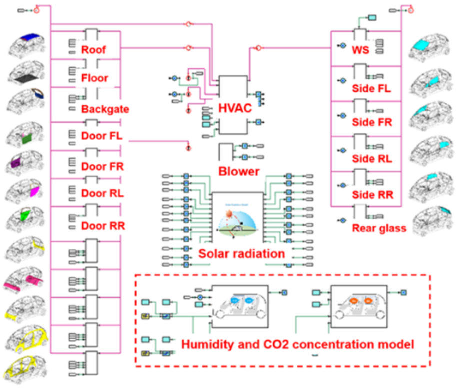


Fig. 5c Chabin Block

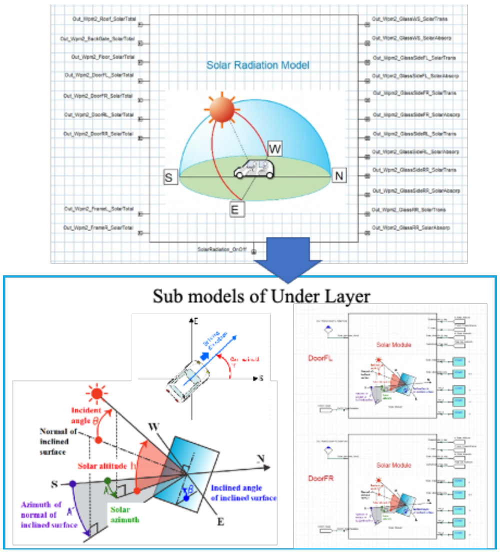


Fig. 5d Sub models of Chabin Block

4. EV vehicle model verification

4.1 Consideration of power consumption and electricity cost associated with mode driving for vehicle development.

Fig. 6 shows the results of comparing the driving distance per charge between an actual vehicle and a simulation for an EV vehicle model that incorporates the specifications of a certain vehicle. The conditions were driving at room temperature with the air conditioning turned off. As a result, the simulation result was 164.8 km per charge, compared to the certified value of 164 km per charge, a result that compares favorably. When these results were verified using more vehicle models, almost the same results were obtained.

Vehicle Name	OEM	EV Motor	Motor Specs Rated Output Max. Output Max. Torque	Battery	Final Reduction Ratio	Vehicle Weight (kg)	Cd	Mode Operation	AER(All Elctric Range) (km) Sim. (km)	AER(All Elctric Range) (km) Spec.(km) MLIT inspection value.
A	JP	RWD AC Synchronous Motor	30kW 47kW 180Nm	16 kWh 48.5 Ah 330 V	7.06	1250	0.28	JC08	164.8	164

Fig.6 Comparison of mileage per full charge

4.2 Air conditioning load due to solar radiation, etc. for practical power consumption consideration.(4),(5)

Consideration of temperature of each part due to solar radiation, etc., and power required for heating and cooling.

In order to discuss the air conditioning load, this model can handle the flow of heat between each part of the cabin of a car and the outside air, as shown in Fig.5c. To verify this model, the temperature change of each part when the vehicle was left in the hot sun for about 4 hours (Fig.7a) and then the air conditioner was turned on is compared between actual measurement and simulation results, and the results are shown in Fig.7c(parts inside the cabin) and Fig.7d (occupant position). In both graphs, the dotted lines are actual measurements, and the solid lines are calculated values using the model. Since the solar radiation azimuth angle and the direction of the surface receiving solar radiation are also included in the calculation factors, and the amount of heat received is also included in the calculation, the temperatures of each part of the cabin and the temperature inside the cabin match well with the estimated values, and it functions to estimate the air conditioning load for heating and cooling.

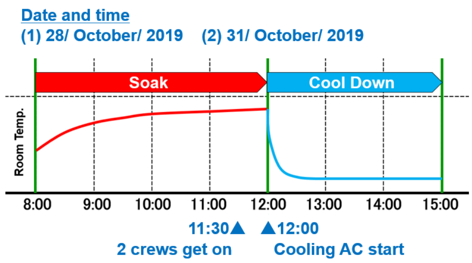


Fig.7a Time and schedule

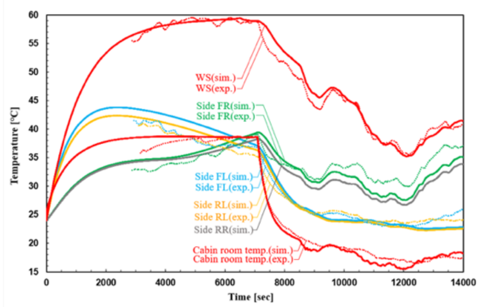


Fig.7b Temperature of each part of the cabin (9)

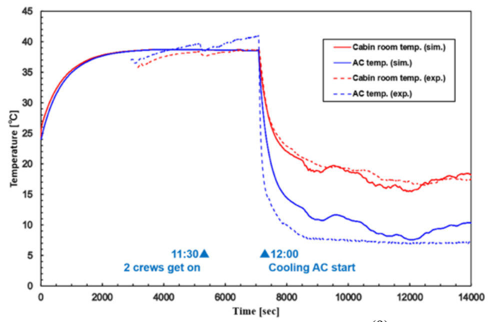


Fig.7c Temperature of the cabin (9)

Therefore, we carried out a trial calculation to see how much equivalence could be shown with a model that includes air conditioning loads for the discrepancy between catalog electricity consumption and actual measured electricity consumption, which was introduced in Figure 4 in the previous section.

The trial calculation conditions were an electric vehicle shown in Figure 6. In this case, the model runs 164km on a single charge, repeating the JC08 mode until the running power runs out. In this case, the model runs once in JC08 mode. The temperature conditions are a room temperature of 25°C, an outside temperature of -10°C when running in China, a maximum output of 4kW for the PTC heater for heating the HVAC interior, and solar radiation is "on." The results are shown in the graph in Figure 8a below. When running at room temperature, the consumption is 2.83MJ, while when heating, it is 6.25MJ (a difference of 3.37MJ), which is 2.2 times the consumption. In other words, the distance that can be traveled with the same energy is 45% when the energy is 2.2 times higher, and although the conditions are slightly different from those of the benchmark test in China, it is not surprising that the actual measured value was about 50% of the catalog value in Figure 8a. Also, Figure 8b shows that the electric energy for heating the room was 3.18 MJ, indicating that the main cause of the deterioration of electricity consumption in cold weather is air conditioning.

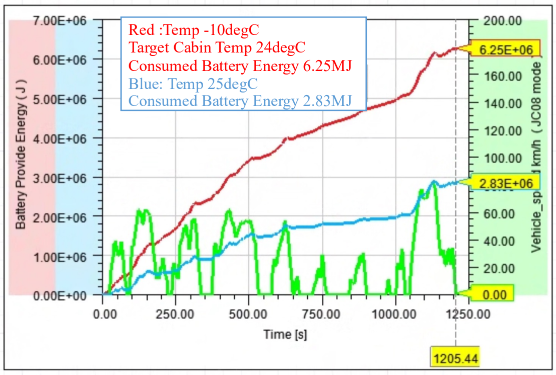


Fig.8a Consumed Battery Energy for JC08 mode running

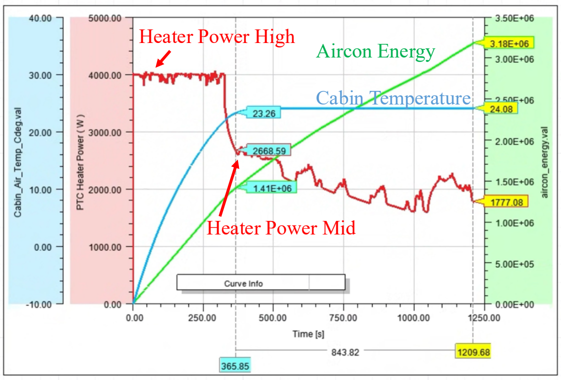


Fig.8b Cabin Temperature, Heater Power and Aircon Energy

4.3 The effect of hill climbing on electricity consumption when considering practical electricity consumption.

Electricity consumption and CO2 emissions when driving in urban areas. We will introduce the driving environment (influence of hill climbing, etc.), main engine battery temperature characteristics (10), driving and CO2 emissions. In the urban area near Yokohama shown in Fig.9a, the driving distance was 45.3 km, the driving time was about 1 hour and 20 minutes, the average vehicle speed was 34 km/h, and the outside temperature was 16 °C.

The battery temperature rose (6.94 calculated/6.9 measured) °C, and the achieved SOC was (53.49 calculated/53 measured) %.

In addition, the route had some ups and downs, and when we compared inputting these ups and downs into the vehicle model (Fig. 9b) with and without them being taken into account (Fig.9c, Fig.9d), the simulation characteristics that took these ups and downs into account showed the same behavior as the actual measurements.

Fig.9a City Driving Route

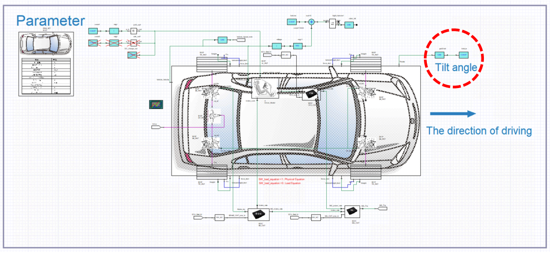


Fig.9b Vehicle model with Tilt Angle

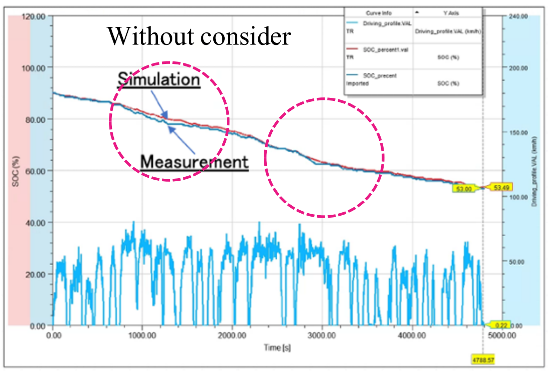


Fig.9c SOC characteristic without consider slope

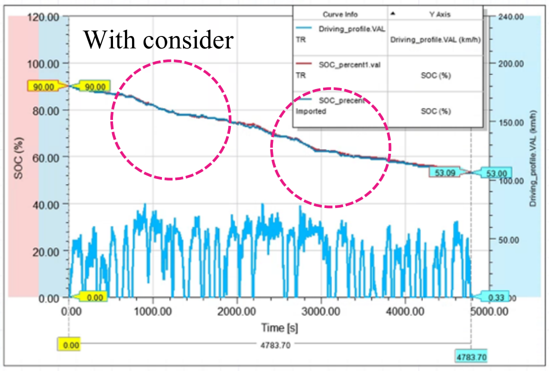


Fig.9d SOC characteristic with consider slope

An enlarged view of this part is shown in Fig.9e. From the figure, we can see that when going up a slope, the car is subjected to slope resistance, and a lot of power is taken up to climb the slope, but conversely, when going down, the car is pushed, and power is reduced.

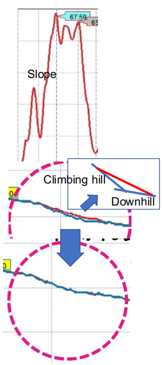


Fig.9e Enlarged view

Next, the temperature of the main battery while it was being driven is shown in Fig.10. Due to space limitations, we will not go into detail about the thermal model here (Reference: Japan Automobile Technology Association paper (6).) During this 1 hour and 20 minutes urban drive, the temperature rose by 6.9°C due to self-heating. This coincides with the actual measurement. This could be used to verify the performance of the main battery at low temperatures, or for protection at high temperatures.

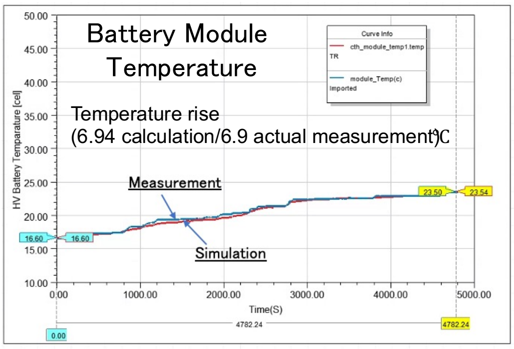


Fig.10 Main Battery Temperature Characteristic

4.4 Power performance.

I have talked about the electricity consumption performance of EVs, but I will now write about another important element of a car: power performance. On a certain road (Fig. 11b), we accelerated to 90km/h over a 400m section. The calculation result (Fig. 11c) for a flat road showed that the calculation reached 90km/h faster.

Conditions: Vehicle weight 1070kg +100kg (passengers + instruments)
Differential gear ratio 7.06
Tire RRC 7.5 N/KN (estimated)
Tire inertia 1.1 kgm2 (estimated)
Tire radius 0.275 m
Full projected area 2.11m2
Air density 1.2kg/m3
Drag coefficient 0.28 (estimated)
Battery voltage 330V
Drive motor inertia 0.1kgm2 (estimated)
Drive motor power generation constant 0.349V/rad/sec (0.0365V/rpm)
The range where the tires do not slip

Fig.11a Condition of Power Performance

When we actually looked at the gradient of the road, we found that it was an uphill gradient of about 15m over 400m, and had an S-shaped gradient characteristic (Fig.11d).

When we applied the approximate formula for this gradient to the gradient input in Fig.11b and calculated the results, the actual measurements and the calculated results matched well (Fig.11e). This result confirmed the possibility of using this as an alternative to power performance testing in the range where slippage does not occur.

Fig.11b Acceleration Test Route

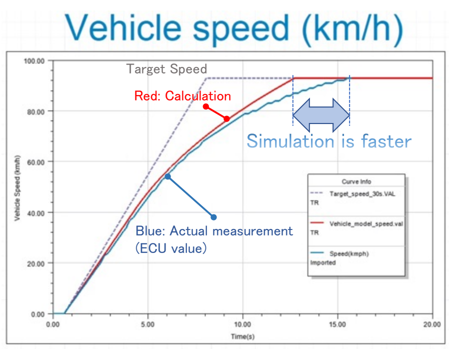


Fig.11c Calculated as a flat road result

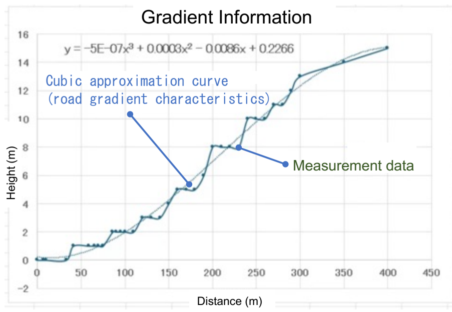


Fig.11d Road gradient measured using GPS data

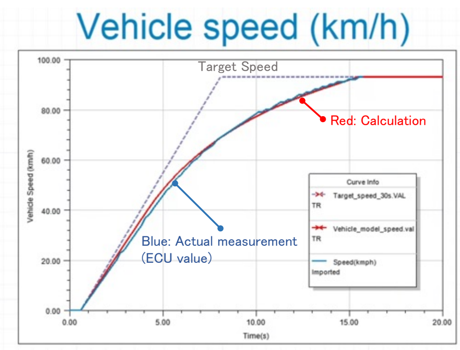


Fig.11e Calculations that take Gradients into Account

4.5 Visualization on a CO2 scale. Electricity consumption and equivalent CO2 emissions.

The behavior of SOC shown in Fig.9d is the result of the accurate representation of the load model consuming electricity. Based on primary energy such as electricity, it is easy to calculate emissions using the power company's CO2 emission coefficient, and the equivalent emissions in real time can also be discussed.

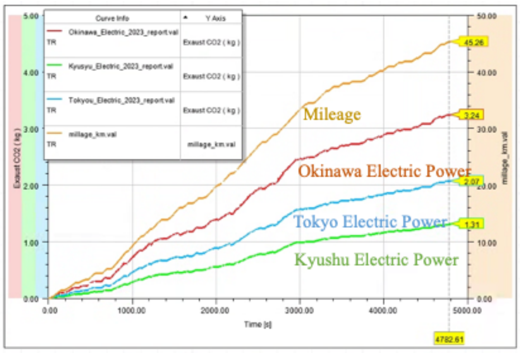


Fig.12 CO2 Emissions Based on 2023 report

Fig. 16 shows the equivalent CO2 emissions from driving in urban areas, depending on the power company. The source is the CO2 emission coefficients of each power company for fiscal year 2023 (Okinawa Electric Power 0.638kg/kwh, Tokyo Electric Power 0.408kg/kwh, Kyushu Electric Power 0.258kg/kwh).

EVs are said to be environmentally friendly, but depending on how you obtain the energy, electricity, they will generate CO2. As shown in Figure 2 at the beginning, the situation is the same for all countries except Brazil, Canada, and France, which have a low ratio of fossil fuels in their electricity composition.

From the results of driving in urban areas shown in Figure 16, TEPCO generated the equivalent of 2.07 kg of CO2. According to the Ministry of the Environment's data (7), CO2 per liter of gasoline is 2.32 kg, and 2.07 kg was generated over a 45.26 km drive, so the equivalent gasoline vehicle is 45.26 x (2.32/2.07) = 50.7 km/L. By the way, Okinawa Electric Power Company generated 32.4 km/L, and Kyushu Electric Power Company generated 80.1 km/L.

As discussed above, these values are halved in winter when air conditioning is turned on.

By accurately modeling electricity consumption in this way, it is possible to visualize the CO2 emitted. Similar methods could also be used to calculate CO2 emissions from the operation of factory equipment and CO2 emissions per product, and ensure equivalence.

5. Model-based digital authentication initiatives

As mentioned above, the results of verifying the alternative performance of actual tests and models using an EV model developed under a METI subsidy confirmed the possibility of use in many areas. Certification in actual tests is reaching its limits due to the diversification and complexity of conditions. Therefore, the Society of Automotive Engineers of Japan established the "Model-based Digital Certification Task Force Working Group" within the "Model Development Technology Division Committee by International Standard Description," and in addition to the Society of Automotive Engineers of Japan, we have also invited "ISO International Standard TC292" and private certification organizations to participate in discussions in order to commercialize the technology, and have begun demonstration experiments (Figure 13a).

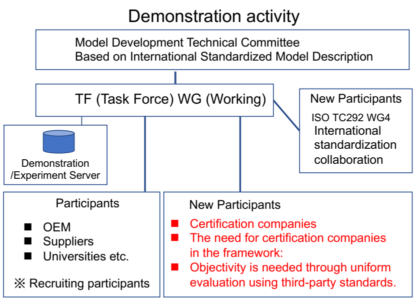


Fig.13a Demonstration Activity for Digital Authentication

The target of the demonstration is to verify off-cycle credits (scheduled to be introduced in Japan from 2030) related to fuel efficiency and CO2 reduction effects in automobiles. Items that are difficult to ensure reproducibility without calculation and items that require a third-party organization to guarantee objectivity using the same procedure (hereinafter referred to as protocol) will be implemented.

These will be carried out in server space, and a third-party certification company will carry out the evaluation using the same protocol and certify that the value is consistent with the value presented by the applicant. In addition, if digital data is tampered with midway, the hash code will change, preventing fraud and tampering.

Figure 13b shows an example of this certification process.

① The target company securely sends the model to the certification organization.

② The certification organization will inspect the calculation model according to the protocol (procedure manual).

③ Models that pass the inspection are passed through a tool to create an encrypted hash value (unique ID), which is embedded in the model as a digital watermark and registered on the public blockchain network along with the inspection information.

④ When the model with the embedded hash is calculated, the hash is also embedded in the result.

⑤ Performance is evaluated using the hash-embedded results, and a report is created.

⑥ The certification body sends the result file and report to the target company.

⑦ The target company compares the hash value in the report with the hash created from its own model, and can file a complaint if it has any doubts.

⑧ If no complaints are made, the evaluation body publishes performance based on the evaluation obtained

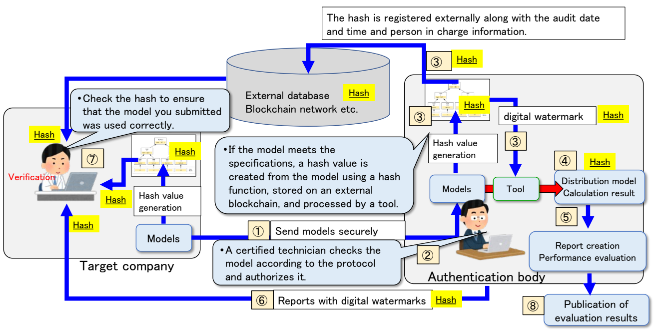


Fig.13b Demonstration Digital Authentication

Here, reflecting on the fact that many of Japan's unique technological proposals have ended up being isolated and not accepted so called "Galápagos" by the world, we are now considering making the digital certification process the same as Euro NCAP [(8)], which is ahead of the competition in crash safety.

Fig.13c shows model distribution example for supply chain. Finished product manufacturer will be able to distributed and use certified part models to certify finished products.

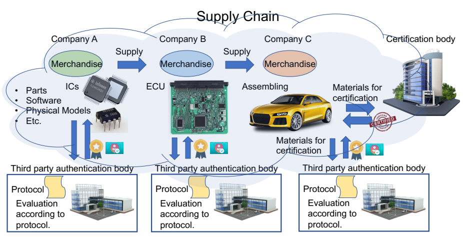


Fig.13c Application for Digital Authentication

6. Summary

Until now, tests and certifications based on actual products have been accepted because they give people a sense of security. On the other hand, the conditions and methods of evaluation have become more diverse, and there have been cases where certification is not based on the actual conditions of the evaluation equipment (time, labor, cost, etc.), and certification is not based on the actual conditions. Therefore, we have started a demonstration experiment aimed at digital certification. This is because the certification is completed in the digital space, and with the advancement of digital technology, it has become possible to realize a system that can leave evidence of tampering.

As off-cycle credits will start in Japan from 2030, this initiative will use an EV vehicle model that was previously discussed, created, and verified by this committee of the Society of Automotive Engineers of Japan as a subject, and will proceed with a demonstration experiment of digital certification with a view to using it for off-cycle credits. This EV model makes it possible to calculate the electric power performance, power performance, and equivalent CO_2 emissions. In particular, the environmental performance of EVs varies greatly depending on the composition ratio of the main electricity sources in each country and the temperature of the environment in which they are used, but this is an excellent tool that can visualize these.

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