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Investigation on Different Driving Cycles and Scenarios Considering the Autonomous Electric Vehicles

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Abstract

This study presents a series of analyzes considering the traction and steering demands of an autonomous electric vehicle (AEV) as a shuttle. The considered analyzes in here are dealt with as driving cycle (DC) and driving scenarios (DS) to assess the traction and steering performance of the AEV. The aim of this study is to evaluate the issues such as over engineering for AEV traction and steering motor requirements on a certain route by comparatively analyzing traditional and dynamic calculation under the DC and DS. Therefore, DC and DS in the literature are evaluated in terms of different applications, optimization techniques, generation algorithm, parametric characterization, e-motor type etc. Afterwards, NEDC, US06, WLTC, Double Lane Change (DLC), Constant Radius (CR) and Slowly Increase Steer (SIS) are determined. Then, they are arranged according to the vehicle-specific limits on an electric golf car. The modified DCs and DSs are run on the dynamic model of the vehicle. In the performed analysis, the parameters such as reference trajectory tracking, yaw angle, tractive and steering forces, lateral and longitudinal displacement-acceleration, steering and traction motor power-speed-torque are investigated. Then the obtained results are evaluated by comparing the traditional calculation results.

Keywords: Driving cycle; Driving Scenario; Autonomous Vehicle; Steering and Traction Dynamics.

1. Introduction

In recent years, interest in emission reduction, clean energy and renewable energy sources has been increasing rapidly. This situation has also accelerated the work on electric vehicles. Especially in the last 20 years, energy efficiency issues have been focused on to increase the range of electric vehicles [1,2]. Energy efficiency basically focuses on alternative battery types, battery management, power electronics drives and electric traction units [3,4].

On the other hand, driving assistants, which have become mandatory to be used with the regulations coming to today's commercial and passenger vehicle concepts, attract a great deal of attention. Driving assistant technologies such as lane tracking, emergency braking and pedestrian detection, and speed limit warnings make it possible to increase the driving safety of passengers and drivers [5]. By the development of driving assistant technology, the interest of the unmanned autonomous vehicle technologies is increased rapidly. Today, vehicles with internal combustion engines, hybrid vehicles and electric vehicles have many driving assistant technologies. In particular, it is seen that some electric vehicle manufacturers focus their efforts on making their vehicles autonomous, that is, they invest in developing fully autonomous electric vehicles. Considering the autonomous vehicle, especially autonomous electric vehicles, the basic work is concentrated on the control of the lateral and longitudinal vehicle dynamics [6]. As longitudinal vehicle dynamics basically controls the acceleration and braking demands of the vehicle, it can already be evaluated in the same concept as normal electric vehicles. On the other hand, the lateral vehicle dynamics control tries to meet the demands on the steering of the vehicle. Thus, the steering with the electric motor stands out in autonomous vehicles [7].

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Therefore, the development of the electric motor drive units for traction and steering, especially in autonomous electric vehicles, directly affects driving performance and safety and the use of energy resources.

Design and optimization studies on electric motors on electric vehicles are mostly subject to component-based verification processes. In recent years, optimization studies for electric vehicles both component-based and system-based have shown that electric traction motors improve design [8,9].

On the other hand, the studies related to autonomous vehicles

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mostly deal with issues such as path tracking, path following, path planning, sensor fusion and improved sensing [10]. In the literature, it has been seen that some steering with e-motor studies are component-based within the scope of driving support [11].

The obtained data from the literature review show the driving performance of traction and steering motors on autonomous electric vehicles (maneuverability, acceleration and braking, battery consumption performance, reference trajectory tracking, etc.), in different driving cycles (ECE R15, NEDC, EUDC, FTP75, etc.). US06 etc.) [12] and different control methods (Pure Pursuit, Model Predictive Control and Stanley etc.) [13] for path tracking could not find any studies on system-based validation.

It is obvious that suitable and optimal electric motors will directly affect the traction and steering dynamics, increase driving performance and driving safety, and increase autonomous driving sensitivity. In this study, it is planned to evaluate an autonomous

Map Based Linear Estimation Strategy

Annealing Optimization Algorithm

Markov Chain Process, State Code Method

Fuzzy Logic, LVQ(Learning Vector Quantization)

Markov Chain Process (MC)

K-Means Clustering Method

Microstrip Analyses Journey Mapping electric vehicle on the power demand needed in different driving cycles and scenarios. The contribution of this study to the literature is to analyze traction and steering demands, to identify potential opportunities and to prevent overengineering.

2. Driving Cycles and Scenarios

Many studies have been done on the driving cycle in the literature. Studies on the driving cycle can be grouped into two categories. These are studies for derivation/generation of driving cycles [14-43] and studies for analysis and optimization of element such as vehicle or component performance under driving cycles [44-74].

The studies on deriving the driving cycle [14-43]; the discussed driving cycles can be evaluated in terms of vehicle types, techniques used and the analyzed parameters. These are given in Tables 1-4.

							5 - 7 []					
Artemis 150 Cyc-US06									FTP-75			
Brun	swick-cycle			Cyc-US06-HWY				H	HDD-Cycle-Creep-Mod	le		
Cyc-	ARB02			Cyc-VAI	L2N	IREL		HHDDT-Cycle-Cruise-Mode				
Cyc-BUSRTE				Cyc-WV	JCI	TY		HHDDT-Cycle-Transient-Mode				
Cyc-	CLEVELANI)		Cyc-WV	JIN	TER		HWY				
Cyc-	CSHVR-Vehi	cle		Cyc-WV	JSU	JB		he	heavy-duty highspeed cycle			
Cyc-	HL07			CTBDS_	UD			he	avy-duty cycle in sub	urb		
Cyc-	HWFET-MTN	1		CWTVC				he	avy-duty interpolation	cycle in urban		
Cyc-	IM240			California	ı-Uı	nified-Cycle		JC	208			
Cyc-	ndia-hwy-san	nple		City-Subu	ırba	in-Heavy-Vehic	cle-Cycle	JE	205			
Cyc-	ndia-urban-sa	mple		Chinese	ypi	cal city		Jaj	pan 10-15			
Cyc-	NREL2VAIL			Beijing-c	ycle	•		M	agny-Cours racing circ	cuit		
Cyc-	NurembergR3	6		Changchu	ın-c	ycle		M	Manhattan-test-cycle			
Cyc-	NYCC			Dalian				New-York-Composite-Cycle				
Cyc-	NYCCOMP			Guangzhou Driving Cycle				New-York-Bus-cycle				
Cyc-	NYCTRUCK			Shangai Driving Cycle				Orange-County-Bus-Cycle				
Cyc-	REP05			Tianjin (Congested, highway, mixture)				SC03-Supplemental-FTP				
Cyc-	SC03			Zhuzhou				stop-and-go cycle				
Cyc-	UDDS			ECE 15				UI	DDS			
Cyc-	UDDSHDV			EPA-Highway-Fuel-Economy-Cycle				US06-Supplemental-FTP				
Cyc-	UKBUS6			EPA-New-York-City-Cycle				WLTC				
Cyc-	UKBUS-MAS	SS-VAR1		FIGE-cyc	FIGE-cycle				WLTC class 3			
Cyc-	UNIF01			FTP-72				WLTP				
					,	Table 2. Vehicl	e Types in [14-43]					
EV	HEV	PHEV		Bus		Truck	Racing Car		Passenger	Test Bench HIL		
				Table 3.	Dri	ving Cycle Ger	neration Technique	s in	[14-43]			
Genetic Algorithm (GA)					Energy Cycle Model with Stochastic and Deterministic Inputs							
SOM Neural Network (Self Organized Mapping)					Stochastic and Deterministic Analyses, Probability Density Function Generation							
Genetic Agency, SVM(Support Vector Machine)					Markov Chain Process, Micro Segmentation							
Neuro-Fuzzy Hybrid Algorithm						Improved Hierarchical Clustering Algorithm, SVM (Support Vector Machine)						
Microstrip Statical Analyses						Microstrip Segment., Markov Chains, Statical-Spectral-Time Domain Analyses						
SOM Neural Network (Self Organized Mapping)					g)	Stochastic Model and Clustering Analyses						

LVQ, DCI model (Driving Cycle Identification)

Driving Behavior Based Optimization

Statical Normal Distribution of Velocity and Acceleration

Markov Chain Process, Stochastic Dynamic Programming

GA, MC, Low Frequency Interpolation, K-Means Clustering

Markov Chain, GA to hybrid MCE (Markov Chain Evaluation) Algorithm

Conditional Probabilities of Acceleration Based on Logistic Regression Models

Parameter Space Based Micro Strip Segment., Clustering, Classification MC

Table 1. Driving Cycles in [14-43]



Table 4. Parametric	Characterizatio	n of the Driving	Cycles in	ı [14-43]
---------------------	-----------------	------------------	-----------	-----------

Look Ahead Distance	Correlative degree of VA distribution (%)	Ratio of speed between 0 to 10 km/h (%)		
Real Driving Emission	Percent of time idling (%) and Time (s)	Ratio of speed between 10 to 20 km/h (%)		
Driver Aggressiveness	Percent of time cruising (%) and Time (s)	Ratio of speed between 20 to 30 km/h (%)		
Route Recognition	Percent of time acc. (%) and Time (s)	Ratio of speed between 30 to 40 km/h (%)		
Drive Cycle	Percent of time decel. (%) and Time (s)	Ratio of speed between 40 to 50 km/h (%)		
Duty Cycle	Travel time / Duration (s)	Ratio of speed between 50 to 60 km/h (%)		
Driving Pattern	Travel distance / Cycle length (m)	Ratio of speed between 60 to 70 km/h (%)		
Driving Profile	Average / Mean Velocity / Speed (m/s)	Ratio of speed between 70 to 80 km/h (%)		
Driving Pulse	Average / Mean Acceleration (m/s ²)	Ratio of speed >80km/h (%)		
Stops per km (s)	Average / Mean Deceleration (m/s ²)	% of time in speed inter. 0 to 5 m/s(%)		
Stop Times	Maximum Velocity / Speed (m/s)	% of time in speed inter. 5 to 10 m/s(%)		
Longest Stop (s)	Maximum Acceleration (m/s ²)	% of time in speed inter. 10 to 15 m/s(%)		
Gradual braking	Maximum Deceleration (m/s ²)	% of time in speed interval > 15 m/s (%)		
Mean Slope (%)	Minimum Velocity / Speed (m/s)	% of time in Acc. Inter. 0 to 7 m/s ² (%)		
Standard Deviation Slope (%)	Minimum Acceleration (m/s ²)	% of time in Acc. interval >7 m/s ² (%)		
Maximal Slope (%)	Minimum Deceleration (m/s ²)	% of time in Decel. Inter7 to $0 \text{ m/s}^2(\%)$		
Minimal Slope (%)	Standard Deviation Velocity / Speed (m/s)	% of time in Decel. interval <-7 m/s ² (%)		
Slope / Road Slope (%)	Standard Deviation Acceleration (m/s ²)	Acceleration >0.1m/s ² Urban (0-60 km/h)		
Cold Start Stop Times (s)	Standard Deviation Deceleration (m/s ²)	Acceleration >0.1m/s ² Rural (60–90 km/h)		
Cold Start Average Velocity (m/s)	Mean velocity during accelerating (km/h)	Acc. >0.1m/s ² Motorway (90-160 km/h)		
Cold Start Maximum Velocity (m/s)	Mean velocity during decelerating (km/h)	RPA (Relative Positive Acceleration) Urban		
Cold Start Maximum Velocity (III/S)	Wear velocity during decelerating (Kill/II)	(0-60 km/h)		
Low Speed Phase (s)	Average Cruising Speed (m/s)	RPA Rural (60–90 km/h)		
High Speed Phase (s)	Average Velocity Urban (m/s)	RPA Motorway (90-160 km/h)		
Traffic Congestion Level	VA Distribution Correlation Coefficient	Time above 145km/h (s)		
Weather Condition	Running speed (except idle speed) (m/s)	Time above 100km/h (s)		
Kinetic Energy unit distance (J/m)	Standard Deviation of Driving Speed (m/s)	Highway time ratio (%)		
Kinematic Sequence of Velocity (m/s)	Positive Acc. Kinetic Energy Change (W)	Medium speed time ratio (%)		
Mean Tractive Force (N)	Mean Positive Velocity (m/s)	Low speed time ratio (%)		
Road Type, Condition, Topography,	Mean Positive Acceleration (m/s ²)	Velocity Noise (Amp., Frequency, Phase)		
Average Climbing (s)	Mean Negative Acceleration (m/s ²)	Mean Power and Energy Need		
Average Downhill (s)	Relative Positive Acceleration (m/s ²)	Mean Power and Maximum Power		
Average Driving Speed (m/s)	Speed Acceleration Frequency Distribution	Driver Action Analysis (Throttle, Brake)		
Vehicle Motion (Turn, Stop-n-Go,	Driver Behavior and Habits (Age,	Driving Scenario (Stop-n-Go, Urban, Suburb		
Acceleration (Acc), Deceleration(Decel)	Experience, Mood, Reflex Time)	an, Rural, Highway)		
Acceleration dependency on speed/gear	Speed variation in free driving	Speed adaptation to the road curvature		

The studies for the analysis and optimization of elements such as vehicle or component performance under driving cycles [44-74]; The discussed driving cycles, the techniques used, the considered motor types, the objective function and the analyzed parameters can be evaluated. These are given in Tables 5-9.

NEDC	NEFZ	Chinese Driving Duty Cycle	Zhuzhou city cycle
J1015	FTP-75	ECE_EUDC Driving Cycle	LUUDC (Loughborough University Urban Drive Cycle)
US06	ARTEMIS	NEDC/Artemis Combined	UDDS (Urban Dynamometer Driving Schedule)
HWFET	jc08	Beijing (China)	US06 (Supplemental Federal Test Procedure/SFTP)
EUDC	FTP72(75)	Karlsruhe (Germany)	Napples Urban Pattern
ECE 15	UC(LA92)	AUDC (Artemis Urban DC)	AEDC (the average efficiency over a driving cycle)
FTP	CADC	NYCC	Bangkok Driving Cycle
WLTC	UNECE R101	HWFET	WHVC
SC03	HWY	REP05	SAEJ227



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		Table 6. E-Motor Types in [44-74]	
PMSM	IPM	Permanent Magnet Assisted Synchronous Reluctance (PMASR)	Induction Motor
IPMSM	SRM	Surface-mounted permanent magnet synchronous motor (SPMSM)	

Table 7. E-Motor Optimization Techniques under Driving Cycles in [44-74]

	-	-			
Frequency Cubic	Central composite des	sign (CCD)	P	SO (particle swarm optimization)	
Genetic algorithm (GA)	Sequential Surrogate Opt	timizer (SSO)	М	ulti-objective design optimization	
Taguchi Robust	Differential Evolution	Algorithm	Multi-	objective genetic algorithm (MOGA)	
Bi-Objective Optimization	Sequential quadratic pro	ogram (SQP)	Multiobjectiv	ve sequential optimization method (MSOM)	
Base point optimization	Loss-minimization a	algorithm	1	Root-mean-square error (RMSE)	
Kriging model using NSGA II	Machine-based minimizat	ion algorithms	Non-domina	ted sorting genetic algorithm II (NSGA-II)	
System-based minimization					
	Table 8. Ob	jective Function	s in [44-74]		
Traction e-motor of	ptimization	Performing	g electric motor	design optimization under driving cycle	
Analyzing driving cycles	in vehicle design	Analysis o	f thermal dama	ages in power-drives under driving cycles	
Investigation of energy efficience	y of electric motor	Investigation	of motor desig	n optimization on temperature-related estima	
design parameters on	driving cycles		ti	on on life cycles	
Investigation of effects on elect	ic motor core materials	Determining t	he relationship	between motor design parameters and	
under driving	cycles		driving cycle	and analysis of fuel economy	
Electric motor design optimiz	tion and cooling unit	Effect of	of motor therma	al change on performance and energy	
design under the	rmal load			consumption	
Investigation of the difference	s between real world	Analysis of d	ifferences in re	eal time driving cycles between Beijing (Chi	
driving cycles and stand	ard driving cycles		na) and	d Karlsruhe (Germany)	
Analysis of the effec	on emissions	An algorithm study to minimize system-level power-driver losses			
Powertrain and fuel consum	iption improvement	Analyzing motor loss patterns under driving cycles			
Analysis of real time optimu	n torque distribution	D.C	, ·		
strategy under dr	ving cycle	Perform	ance analysis of	of fuel efficiency under driving cycles	
Analysis of the performance of	powertrain topologies	Investi	gation of the o	ptimal driving cycle for designing a	
	cycles		nign-perio	imance hybrid powertram	
	Table 9. E-Motor Parametri	ic Analysis unde	r Driving Cycles	s in [44-74]	
Average Vehicle Trip Speed	Co	pper Loss		Battery Energy/Distance	
State of Charge	Driving Cycle Regimes	s (Highway, Sub	Damage - Distance to Failure		
Efficiency	Power	Consumption		Heat Generation Rate	
Core loss	Fuel C	Consumption		Power Loss	
Temperature	Fuel S	Saving Ratio	Power Delivered		
Flux Density	Re	otor Flux		Starting	
Peak Power	Cumulati	ive Energy Loss	Acceleration		
Rated Power	Dr	rive Loss	Climbing		
Peak Torque	Inv	verter Loss High Speed			
Fuel Economy Improve Rate	Fi	lter Loss		Normal Cruise	
Torque-Speed Map	Trac	ction Power		High Torque	
CO ² Nitrogen Emission	wer Range		Low Torque Ripple		
Thermal Model	A Trajectory		Strong Fault Tolerance		
Lifetime Model	V Trajectory		Wide Speed Range		
Hot Spot Temperature	ase Speed		High Efficiency		
Torque-Speed Loss Map	Overlo	ad Capability		Star or Climbing	
Energy-Torque-speed Map	Mecha	anical Energy		Normal Operation	
Iron Loss	Low-Mid	ldle-High Speed		Open-Circuit Fault	
Id-Iq Currents / D-Q axis	Wheel E	Energy/Distance		Start-circuit Fault	
Winding Temperature	Brake Event /	Acceleration Ev	vent	High Speed Operation	

Basically, the driving cycle consists of 4 main components. These are acceleration, deceleration, idle and cruise. Driving cycles are obtained by arranging these components sequentially to form a cycle. An example for drive cycle components is shown in Figure 1 and it is used for various purposes to analyze the elements such as emission and battery consumption. In the studies conducted between [14-74], the vehicle development processes both component-based analysis of driving cycles and system-level analysis studies are focused. These driving cycles are previously used



for vehicles with internal combustion engines. With the widespread use of electric and hybrid vehicles, it has started to be used in basic performance tests here.

One of the main problems in the driving cycle is that the uphill and downhill tests cannot be observed, so it is tried to analyze the sudden acceleration and deceleration components in the driving cycles, although not fully, the effects of these factors. In addition, there are some analysis studies in the literature [75], which are designed in ECE R15, for the downhill and climbing analysis. A driving cycle with slope scenario is given in Figure 2.



(b) Driving Cycle

Fig 1. Driving Pulse and Driving Cycle Pattern [23]



Fig 2. Driving Cycle with Slope Pattern [75]

On the other hand, with the development of driving assistant and autonomous vehicle technologies, driving scenarios are also needed for testing and analysis. Especially when autonomous electric vehicles are considered, driving cycles or driving scenarios including test maneuvers are needed.

The observed standards from the literature [76];

- Swedish Standards Institute containing ISO standards
- SAE International Digital Library
- FMVSS, Federal Motor Vehicle Safety Standards (Sine with dwell FMVSS216)
- EuroNCAP (information regarding ESC standard)
- NHTSA (information regarding ESC standard)
- ISO/TC 22 Road vehicles (Relevant parts regarding passenger cars.)
- Motor sport magazines (e.g. Acceleration 0 100 km/h)

To evaluate the most useful test maneuvers for a vehicle-based study, the tests that can be used to validate a real vehicle behavior and the tests that can be used to validate a vehicle model and demonstrate model limitations are listed as follows [76];

- Steady state cornering ISO 4138
- Sine with dwell FMVSS126 S7.9
- Fishhook NHTSA (FEO05)
- Sine steer increased amplitude (FEO05)
- Double lane change ISO 3888-1
- Sinusoidal input, one period ISO 7401 (ISO 8725)
- Obstacle avoidance ISO 3888-2
- Step input ISO 7401
- Pulse input ISO 7401
- Random input ISO 7401 (ISO 8726)
- Continuous sinusoidal input ISO 7401
- Stopping distance at straight-line braking with ABS ISO 21994:2007
- Braking with split coefficient of friction ISO 14512
- Brake in a turn ISO 7975
- Power off reaction of a vehicle in a turn ISO 9816
- Acceleration 0-top speed
- Accelerating with split coefficient of friction
- Accelerating in a turn

3. Vehicle Model

The vehicle model that is considered to be used in this study is a 5+1 persons golf vehicle. The details of the vehicle properties are given in Figure 3(a). The reason for choosing this vehicle is to meet the service needs in large areas such as schools, hospitals and airports as an autonomous service vehicle.

Figure 3(b) shows the dynamic simulation model of this vehicle. Here, the study is carried out on a dual track vehicle model with 3 degrees of freedom. As seen in Figure 3(b) for the traction part, the vehicle is driven on the powertrain and wheel model. The traction force accelerates the vehicle body by overcoming the opposite force such as air friction, rolling and slope. It is represented from equation 1-4 [77].

$$m.\frac{dv_{veh}}{dt} = f_{veh} - (f_{rol} + f_{wind} + f_{grad}) \tag{1}$$

$$J_w.\frac{d\omega_w}{dt} = T_d - r_w.f_{veh} \tag{2}$$

$$T_d = \eta . T_m . n \tag{3}$$

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(4)

$$T_m = P_{out}/\omega_m$$

The applied input torque is equal to the sum of the axle torque, braking torque and traction torque [77-81].

$$T_i = T_a - T_b + T_d \tag{5}$$

In the steering part, steering is carried out with the rack and pinion system. According to the driving scenario, the steering and traction parts are tried to be controlled with the control signals (Lateral (Yaw Rate) and Longitudinal (Reference Velocity)) produced by the driver. In this case, the transferred torque through the

$$T_{sw} = -GK_m i + T_r + J_p a_p + c_p \cdot \omega_m / G \tag{6}$$

The vehicle model shown in Figure 3 (a) uses DLGF 122200-4 of ABM company for traction. The rated specification of DLGF 122200-4 are 10 KWatt (KiloWatt), 20 Nm (Newton.meter) and 5000 RPM (Revolutions Per Minute). For steering, the vehicle model shown in Figure 3 (a) uses EPAS18 of DC Electronics company. The rated specification of EPAS18 are 0.45 KWatt, 34.5 Nm and 130 RPM.



b) Dynamic Model of the Vehicle

Fig 3. Vehicle Model a) Specification of the Vehicle b) Dynamic Model of the Vehicle

4. Methodology

A generalized representation of the autonomous vehicle architecture is given in Figure 4. Since this study focuses on the traction and steering part, it is planned to carry out operations with the driving cycle in the traction part and with the driving scenario in the steering part. Therefore, the representation of the driving cycles and driving scenarios discussed is given in Figure 5.

As can be seen from Figure 5, the performed analyseis in this

study are dealt with two parts as traction and steering. Here, 3 different driving cycles are selected for traction. These are NEDC, US06 and WLTC Class 3 Low. Since the vehicle whose model is considered as a golf cart and it has a maximum of 25km/h, the 3 driving cycles are arranged to be evaluated on a similar time scale in accordance with the vehicle specification and adjusted according to the maximum speed.

On the other hand, Double Lane Change [84], Constant Radius



[85] and Slowly Increase Steer [86] are discussed in order to evaluate the maneuver for the steering part. Here, the driving scenarios are arranged similarly in accordance with both vehicle dynamics and maximum speed.

By running on both Driving Cycles and Driving Scenarios dynamic vehicle model, the parameters such as displacement, reference trajectory tracking, acceleration, yaw angle, tractive force, traction motor power-speed-torque, steering force, lateral displacement, lateral acceleration, steering motor power-speed-torque are dealt with and tried to be analyzed.





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5. Results and Discussion

The main purpose of this study is to analyze the customized motor for autonomous electric vehicles that will work on a certain road profile for service purposes, instead of using the motor determined by overengineering as a result of traction and steering motor calculation. Therefore, in an autonomous electric vehicle, the selection of traction and steering motors with traditional calculations are compared and analyzed in driving cycles and scenarios.

For the traction analysis under NEDC, US06 and WLTC, the obtained results and the detailed information are shown in Figure 6. For the steering analysis under Double Lane Change, Constant Radius and Slowly Increase Steer, the obtained results and the detailed information are shown in Figure 7.

The obtained results from traction and steering analysis under the driving cycles and scenarios are summarized in Table 10 and Table 11. Here, the performance of traction and steering analyzes are evaluated relatively by 3 metrics to simplify the overall performances. For the traction, as shown in Table 10, WLTC forces the vehicle model to operate higher performance in comparison with NEDC and US06. On the other hand, for the steering analysis, CR and SIS force the vehicle model to operate higher performance in comparison with DLC.

			-		· · · · · · · · · · · · · · · · · · ·				
Traction	Displacement	MSE for	Max	Lateral	Tractive	Motor	Motor	Motor	Overall
Analysis	Error	Tracking	Acceleration	Deviation	Force	Torque	Speed	Power	Scores
NEDC	GOOD	GOOD	LOW	BETTER	HIGH	GOOD	GOOD	MID	GOOD
US06	BETTER	BETTER	HIGH	GOOD	LOW	GOOD	GOOD	LOW	BETTER
WLTC	GOOD	GOOD	HIGH	BEST	HIGH	GOOD	GOOD	HIGH	BEST

Table 10. Traction Analysis under NEDC, US06 and WLTC

Steering	Correlation	Steering	Max	Lateral	Lateral	Motor	Motor	Motor	Overall
Analysis		Force	Speed	Deviation	Acceleration	Torque	Speed	Power	Scores
DLC	BEST	LOW	MID	LOW	LOW	LOW	LOW	LOW	GOOD
CR	GOOD	MID	HIGH	HIGH	HIGH	MID	MID	MID	BEST
SIS	GOOD	HIGH	LOW	HIGH	MID	HIGH	HIGH	HIGH	BEST

Table 11. Steering Analysis under DLC, CR and SIS

Constant

Radius

Slowly

Increase

Steer

Traction Analysis



Dynamic

Model

728

5.78

200

22.94 170.88

2.8

28.4

22.94

Fig 5. Methodology of Traction and Steering Analysis

Driving Scenerio

Assesment

Distance (meter)

Distance (meter)

ed (m/s)

Max Deviation on Y axis (m)

Max Deviation on Y axis (m)

Unit Kinetic Energy (J/m)

Unit Kinetic Energy (J/m)

Speed (m/s)

Scaled

Scaled

Arrangement

Considering the obtained findings, it is necessary to compare the DLGF 122200-4 traction motor selected for the vehicle model and the demanded motor requirements during the driving cycles as torque-speed and power-speed for each driving cycle. Figure 8 shows the obtained results for the traction analysis. As can be seen from Figure 8, the demanded torque-speed-power is quite below the capacity of the DLGF 122200-4 traction motor. This clearly

Driving

Scenerio

shows that the DLGF 122200-4 traction motor is an overengineering choice. Therefore, with an optimized and customized motor design, it is possible to gain from the design space by having a more compact structure. Besides, gains from power to weight ratio can provide increasing the range of electric vehicles by weight reduction

Save the Results





c) WLTC

Fig 6. Driving Cycle Results for Traction

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c) Slowly Increase Steer (SIS)

Fig 7. Driving Scenerio Results for Steering





Fig 8. Traction Motor Analysis

Similarly, it is necessary to compare the EPAS18 steering motor selected for the vehicle model and the demanded torque-speed-power values in the driving scenarios for the steering analysis. Figure 9 shows the obtained findings for the steering analysis. As can be seen from Figure 9, it is observed that the demanded torque-speed-power is far below the capacity of the EPAS18, so it is an overengineering choice here as well. Although the power consumed on EPAS is very small, considering the electric vehicles and range problems, it is seen that a more efficient and compact design as a result of optimization will increase the efficiency.

6. Conclusions

In this study, the demands of the traction and steering requirements for an autonomous electric vehicle on a predetermined route to be followed within the scope of autonomous duty are tried to be evaluated. Considering autonomous vehicles, the main task is to provide lateral and longitudinal movements with traction and steering. Therefore, traction and steering motors are discussed here. In order to assess the traction part, the driving cycle is needed, and in order to assess the steering part, the driving scenario is needed. Within this scope, the studies in the literature are reviewed and the driving cycles and scenarios are analyzed. The potential driving cycle and driving scenarios are determined by taking into account the dynamics of the electric autonomous shuttle as a result of the evaluations. In order to obtain suitable driving cycles and driving scenarios for the specs of the vehicle, the parameters such as the maximum speed that the vehicle can reach and the driving cycles and driving scenarios are modified and arranged. The dynamic model of the vehicle is modeled in Matlab Simulink in accordance with the specs and it is made ready for analysis.

The parameters such as displacement, reference trajectory tracking, acceleration, yaw angle, tractive force, traction motor powerspeed-torque, steering force, lateral displacement, lateral acceleration, steering motor power-speed are tried to be analyzed on the vehicle model running under driving cycles and scenarios such as NEDC, US06, WLTC, DLC, CR and SIS selected for Traction and Steering analysis. According to the analyzes, it is seen that the obtained results are at an acceptable level for trajectory tracking and other parameters.

On the other hand, it is observed that the traction and steering power-torque-speed values demanded by the dynamic vehicle model, which is run under driving cycles and driving scenarios, are far below the capacity of the DLGF traction motor selected for the vehicle with traditional methods and the EPAS18 steering motor, and an overengineering choice is made. It is seen that the autonomous service vehicle will work on a predetermined path and efficiency will increase with the selection of the optimal steering and traction motors, considering the range problem in electric vehicles.

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Fig 9. Steering Motor Analysis

Nomenclature

m	: vehicle body mass (kg)
T_i	: net input torque (Nm)
T_a	: applied axle torque about wheel spin axis (Nm)
T_b	: braking torque (Nm)
T_d	: combined tire torque (Nm)
T_r	: resistance torque (Nm)
T_m	: torque from electric motor (Nm)
T_{sw}	: steering wheel torque (Nm)
η	: efficiency (%95)
n	: transmission ratio (1:8)
G	: transmission ratio (1:4)
a_p	: angular acceleration of steering column (rad/s ²)
c_p	: steering column damping (Nm.s/rad)
J _w	: inertia of the wheel (kg.m ²)
J_p	: rotary inertia of the steering column (kg.m ²)
Pout	: motor output power (watt)
K_m	: motor torque constant (Nm/Amp)
i	: motor current (Amp)
ω_w, ω_m	: wheel and rotor angular speed (rad/s)
ω_p	: angular speed of the steering column (rad/s)
f _{veh}	: traction force (N)
f_{rol}	: rolling resistance (N)
f _{wind}	: aerodynamic drag force (N)
fgrad	: grading force (N)
v_{veh}	: vehicle velocity (m/s)

Conflict of Interest Statement

The authors must declare that there is no conflict of interest in the study.

CRediT Author Statement

Uğur Demir: Conceptualization, Writing-original draft, Validation, Data curation, Formal analysis, Zeliha Kamış Kocabıçak: Conceptualization,

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