Research Article

Modelling of Forklift Drivetrain and Running the Fuel Consumption Cycle

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Abstract

At the very beginning of the design phase of a forklift truck, it must be determined which drive systems will be used. Then, with these drive systems and the target weight, it must be calculated how many litres of fuel the truck burns according to VDI 2198. In this study, a forklift truck will be modelled in MatLab environment with all its sub-systems and run in a cycle in accordance with VDI 2198. One of the biggest outputs of this study will be to know the fuel consumption of this forklift during the forklift design phase.

Keywords: *Forklift, VDI 2198, Fuel Consumption Cycle for forklift, Tractive Effort*

1. Introduction

The components that affect the fuel consumption of a forklift truck are the engine and the drive systems, respectively. Forklifts lift loads with counterbalancing weights, so it is not desirable to reduce the weight of forklifts. Considering these points, it is very important to model the engine and drive systems of a forklift at the very beginning of the design, run a fuel consumption cycle according to VDI 2198 and evaluate the results.
Figure 1 shows the general view of Tümosan 3.5 Ton Diesel Forklift with Tümosan Diesel Engine, which will be equipped with drive systems (Transmission, Torque Converter, Differential and Speed Reducer).

Figure 1: General View of Tümosan 3.5 Ton Diesel Forklift [1]

2. Materials and Methods

2.1.Main Features of Forklift

In this study, Tümosan brand diesel forklift with a load lifting capacity of 3.5 tonnes will be used. The main features of this forklift truck are as shown in Table 1 below.

Table 1: Main Features of Forklift

No	Description		Unit	Value
1	Vehicle Weight	Loaded	kg	8584
2		Unloaded	kg	5084
3	Engine Model		-	3DN-29T-048C
4	Maximum Power		kW	36 @ 2400 rpm
5			HP	48 @ 2400 rpm
6	Effective Wheel Radius	Loaded	mm	318
7		Unloaded	mm	346
8	Vehicle Projection Area		m2	2,7
9	Coefficient of Aerodynamic Resistance (CD)		-	0,8
10	Rolling Resistance Coefficient		-	0,01

The basic forklift truck components separated according to their main tasks are shown in figure 2.

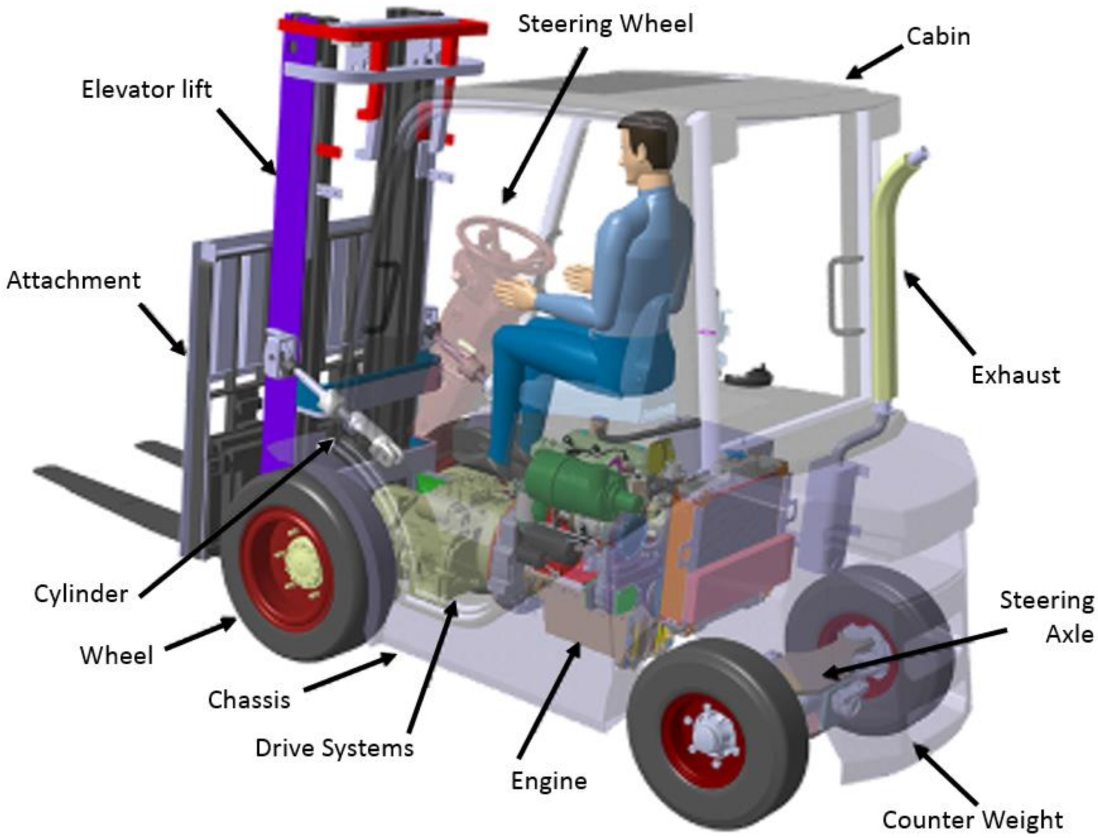


Figure 2: Basic Subsystems of Forklifts

2.2.Diesel Engine

The characteristics of the Tümosan brand diesel engine used in the forklift which is the subject of this study are as shown in Table 2.

Table 2: Characteristics of Diesel Engine [2]

Model	**3DN-29T-048C**
Cylinder Layout	inline
Rated Power @ 2300 rpm	48 Hp
Rated Torque @ 1500 rpm	170 Nm
Total Engine Capacity	2908 cm^3
Diameter x Stroke	104 mm x 115 mm

Number of Cylinder	3
Minimum Specic Fuel Consumption	160 g/Hph
Aspiration	Natural Emission
Number of valves per cylinder	2
Compression Ratio	17:1
Dry weight	300 kg
Wet weight	325 kg
Emission Level	Stage III A
Injection type	Mechanical injection
Cooling System	Water-cooled

The performance curves of Tümosan brand, 3DN-29T-048C coded diesel engine are as shown in Figure 3.[1]

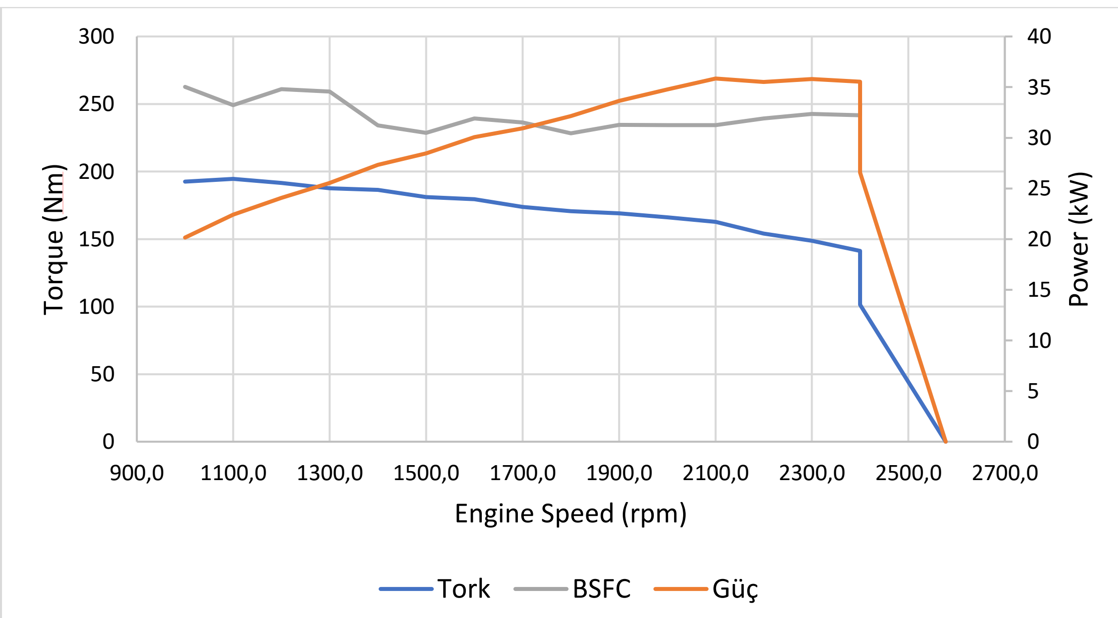


Figure 3: Engine Performance Curves [2]

[1] Due to the confidentiality rules of the company, the engine specific fuel consumption map was not shared directly, but the calculations were made with real values.

2.3.Drive System

Drive systems with different structural architectures are used as drive systems in forklifts, these systems are basically classified as Mechanical, Hydrodynamic and Hydrostatic. The drive system of the forklift, which is the subject of this study; Mechanical System, one of the biggest advantages of this system is the use of a gear pump in the hydraulic system of the load carrying system and since it is a fixed capacity type pump, a constant amount of oil is provided according to the engine speed regardless of the operation of the load carrying system.[3]

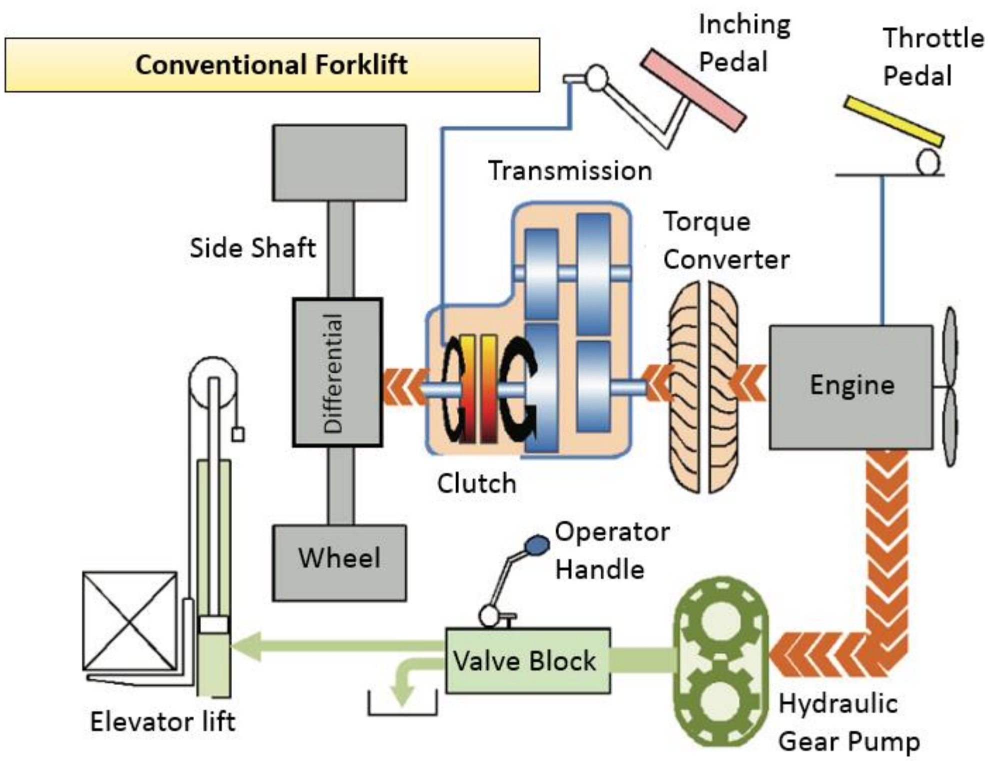


Figure 4: General System Diagram of a Conventional Forklift [3]

As can be seen in Figure 4, the working structure of the conventional mechanical drive system in general terms, both the power for movement and the hydraulic power in the forklift truck are provided by an internal combustion engine. Immediately behind this engine, a transmission with a torque converter is connected, and in this transmission there is often a drive axle connected via a shaft or directly c
onnected, and in this drive axle, the power is transferred to the road as a thrust force through the wheels.

2.4.Transmission

In Tümosan 3.5 tonne diesel forklift, Hyundai brand, torque converter, 1 forward and 1 reverse transmission is used. Technical specifications of this used transmission are shown in Table 3.

Table 3: General features of hyundai brand transmission used in forklift truck [4]

Transmission Brand	Hyundai
Transmission Model	HT30-TS010
Maximum Input Power (kW)	55
Maximum Input Torque (Nm)	620
Type	Full Floated & Power Shift
Torque Converter Type	1 Stage – 2 Phase
Torque Converter Stall Ratio	2,87
Gear Ratio	1,438

The performance curve of the torque converter used in this transmission is as shown in figure 5 below.

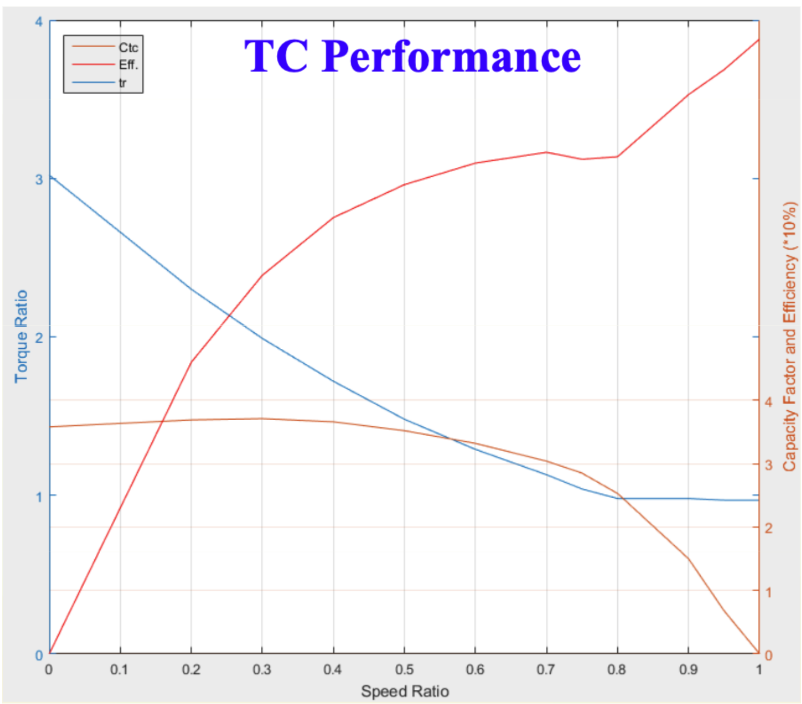


Figure 5: Torque Convertor Performance Curve [4]

2.5.Drive Axle

The cross-sectional view of the drive axle and the cross-sectional view of the differential, right-left shafts and reduction gear are as shown in Figure 6.

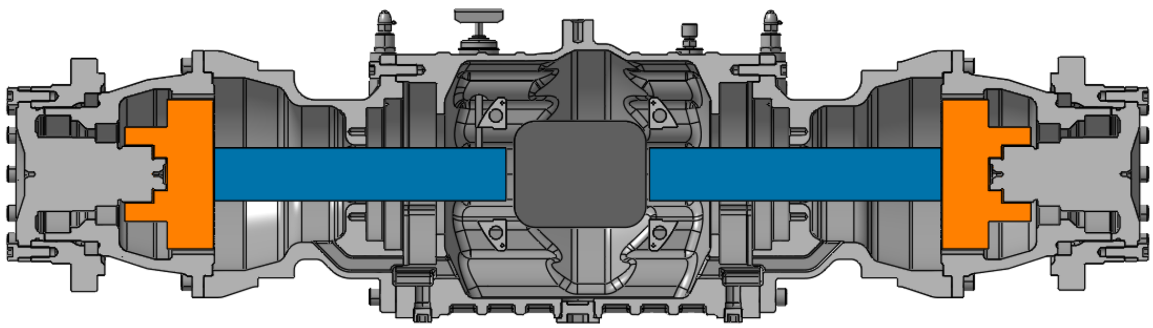


Figure 6: Cross-sectional view of the drive axle [5]

The general characteristics of this drive axle are as shown in Table 2.4.

Table 4: Drive Axle Characteristics [4]

Drive Axle Brand	Hyundai
Drive Axle Model	HA30-TS010
Maximum Input Torque (Nm)	620
Differential Gear Ratio	2,818
Hub Reduction Gear Ratio	4,105

2.6.Power Requirement

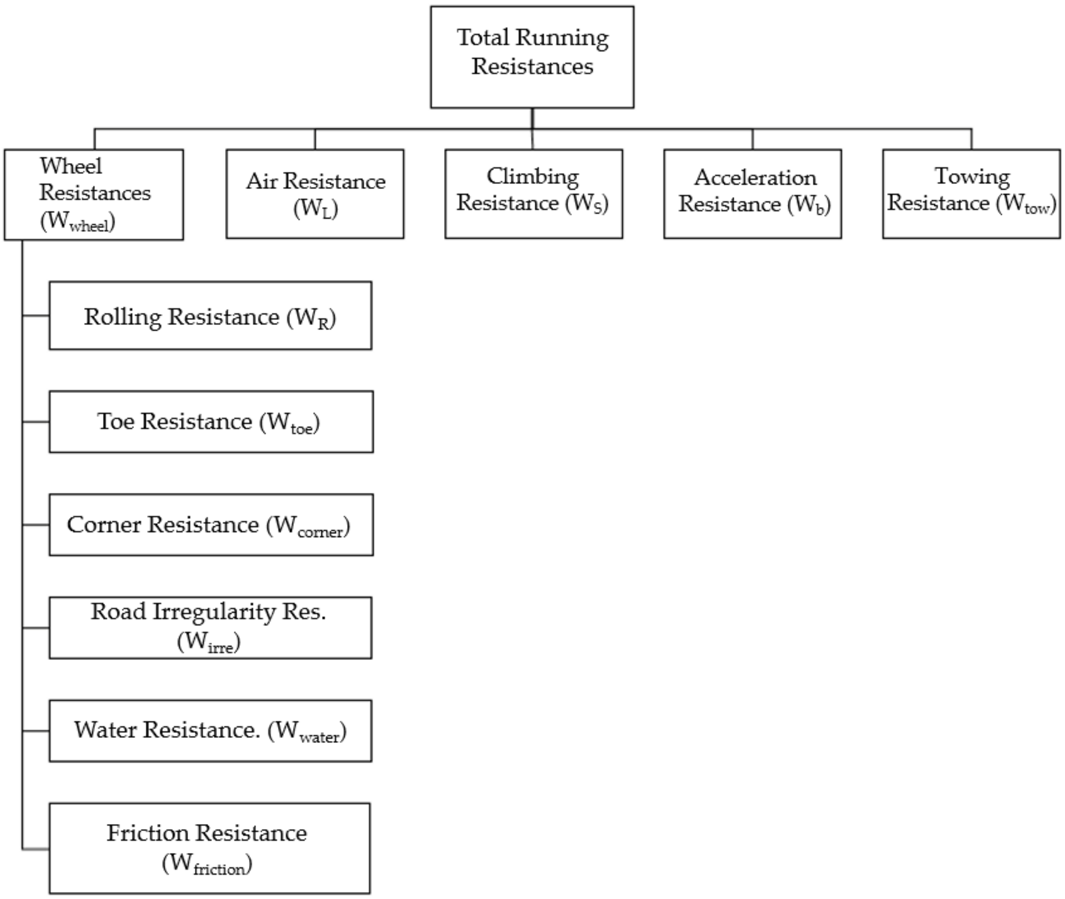
In order for the vehicle to move, the movement condition must be met. In the case where there is no slip between the wheel and the ground, the Power Requirement is expressed as follows. [6]

$$N_e = \frac{\sum W . V_{vehicle}}{\mu_m}$$

2.7.Resistances

The sum of the components of the forces acting in the direction of the vehicle axis, in the opposite direction to the vehicle movement, is called movement resistances. [6] The power requirement required to fulfil the movement condition must be greater than these resistances. In a vehicle design, it is very important to calculate the resistances acting on the vehicle as close as possible to the reality in order to position the vehicle's capabilities correctly during the design phase.

Table 3: Total Movement Resistances Acting on a Vehicle [6]



Total resistances are as shown in the equation shown below;

$$\sum W = W_R + W_L + W_S + W_B$$

The comprehensive representation of the total resistances is also as shown in the following equation; [6]

$$\Sigma W = f_0 . \left(1 + \frac{\left(\frac{V_T}{3.6} \right)^2}{1500} \right) . G.\cos\alpha + \frac{1}{2} . \rho_h . C_D . A . V^2 + G.\sin\alpha + \varphi . m . \frac{dV_T}{dt} + W_Ç$$

2.8.Test Cycle

In the forklift industry, the VDI 2198 standard is widely used for fuel consumption assessment. Energy consumption is influenced by driving parameters such as speed, load, road condition, surface gradient and the vehicle's own weight. The VDI cycle is a specific is a standard used to simulate pick and place cycles without dropping the load to two different locations at a distance. The VDI 2198 standard specifies a speed profile and the speed profile to be performed during the cycle.
does not specify the duration of each operation, but the travelling speed is adapted to observe the specified number of cycles per hour. [7]

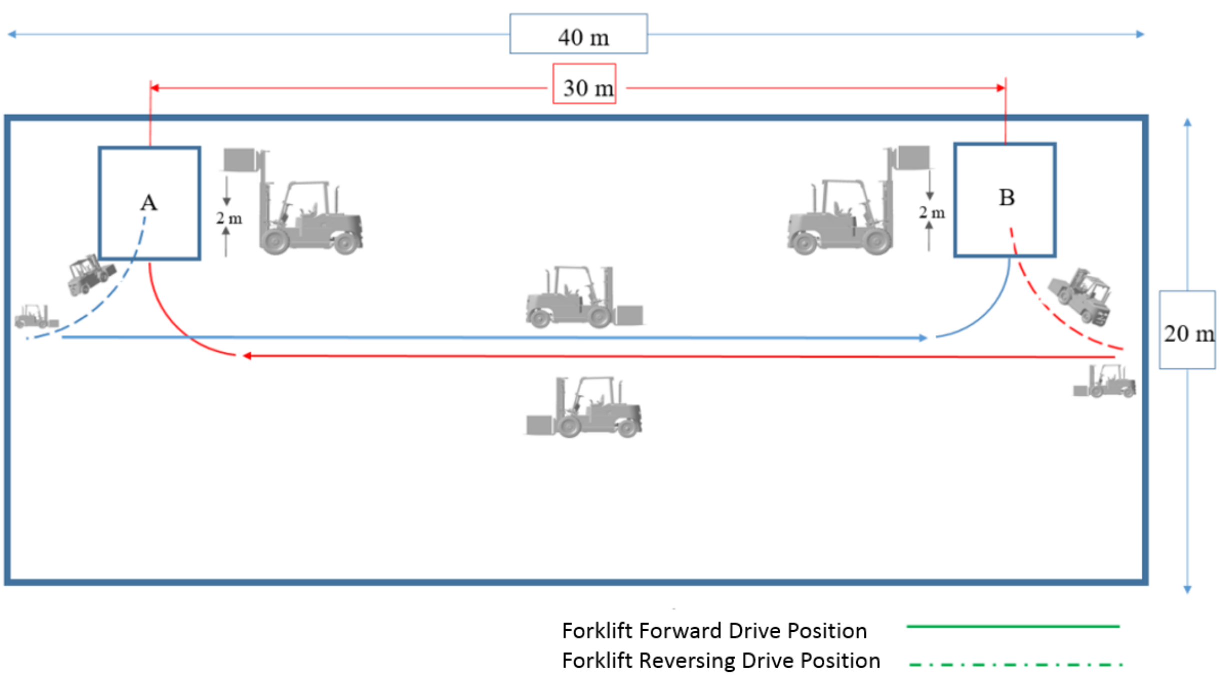


Figure 7: Test Cycle According to VDI 2198 [7]

2.9.Vehicle Model and Algorithm

The forklift truck with the above vehicle specifications was modelled in Matlab. Figure 7 shows how the algorithm is constructed.

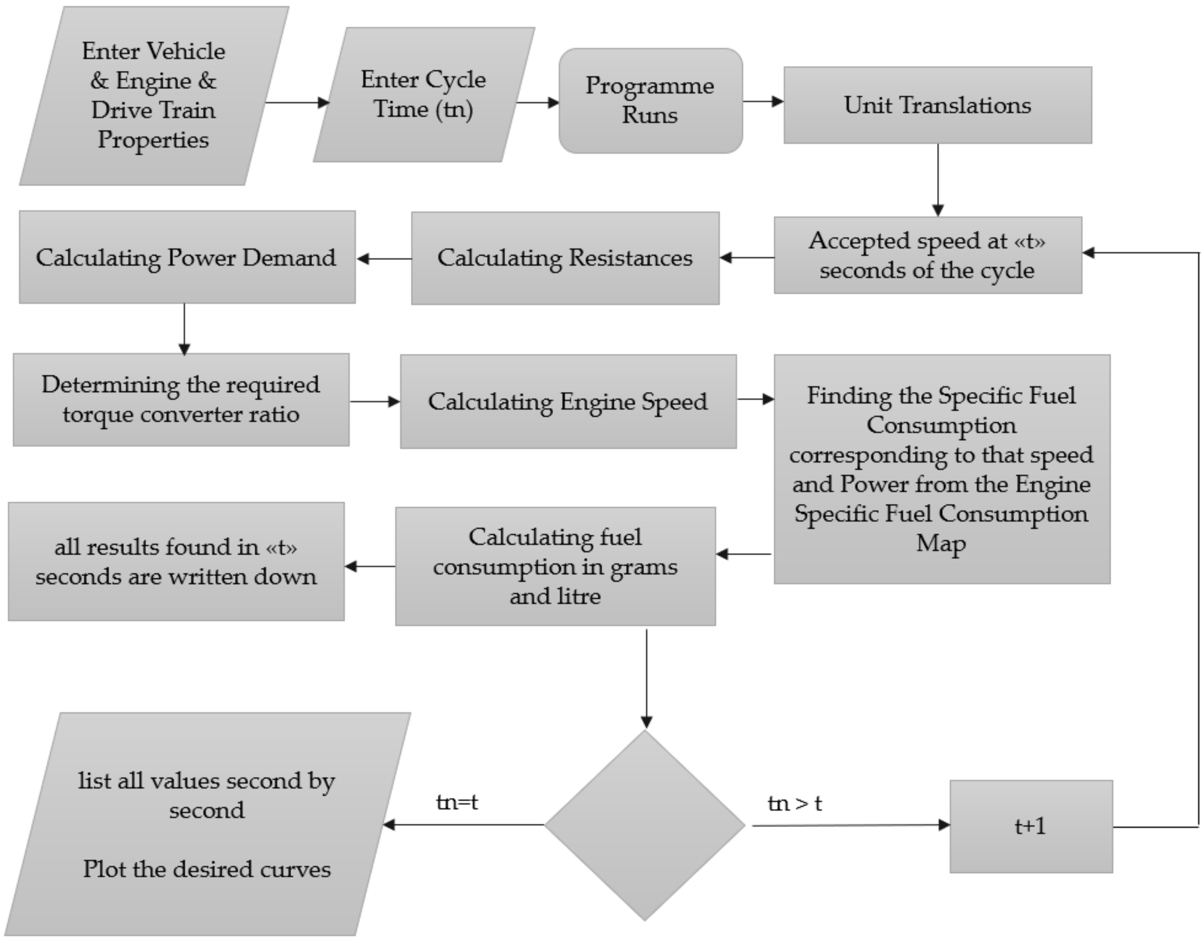


Figure 8: Flow Diagram of the Algorithm created in Matlab

Firstly, vehicle characteristics, engine characteristics and drivetrain characteristics are defined as a constant in the programme. The number of seconds of the predetermined test cycle is entered into the algorithm and the programme starts to run. Firstly; unit conversion operations are performed, then starting from the first second, it accepts the speed across the seconds in the cycle and calculates the resistances affecting the vehicle at this speed, calculates the corresponding power demand, determines the torque converter ratio corresponding to this power demand and determines the residual engine speed. The algorithm goes to the fuel consumption map of the engine and finds how much fuel it consumes at this speed at this power demand. After that, these calculations continue for the time entered at the beginning of the cycle and the desired values will be presented cumulatively at the end of the cycle.

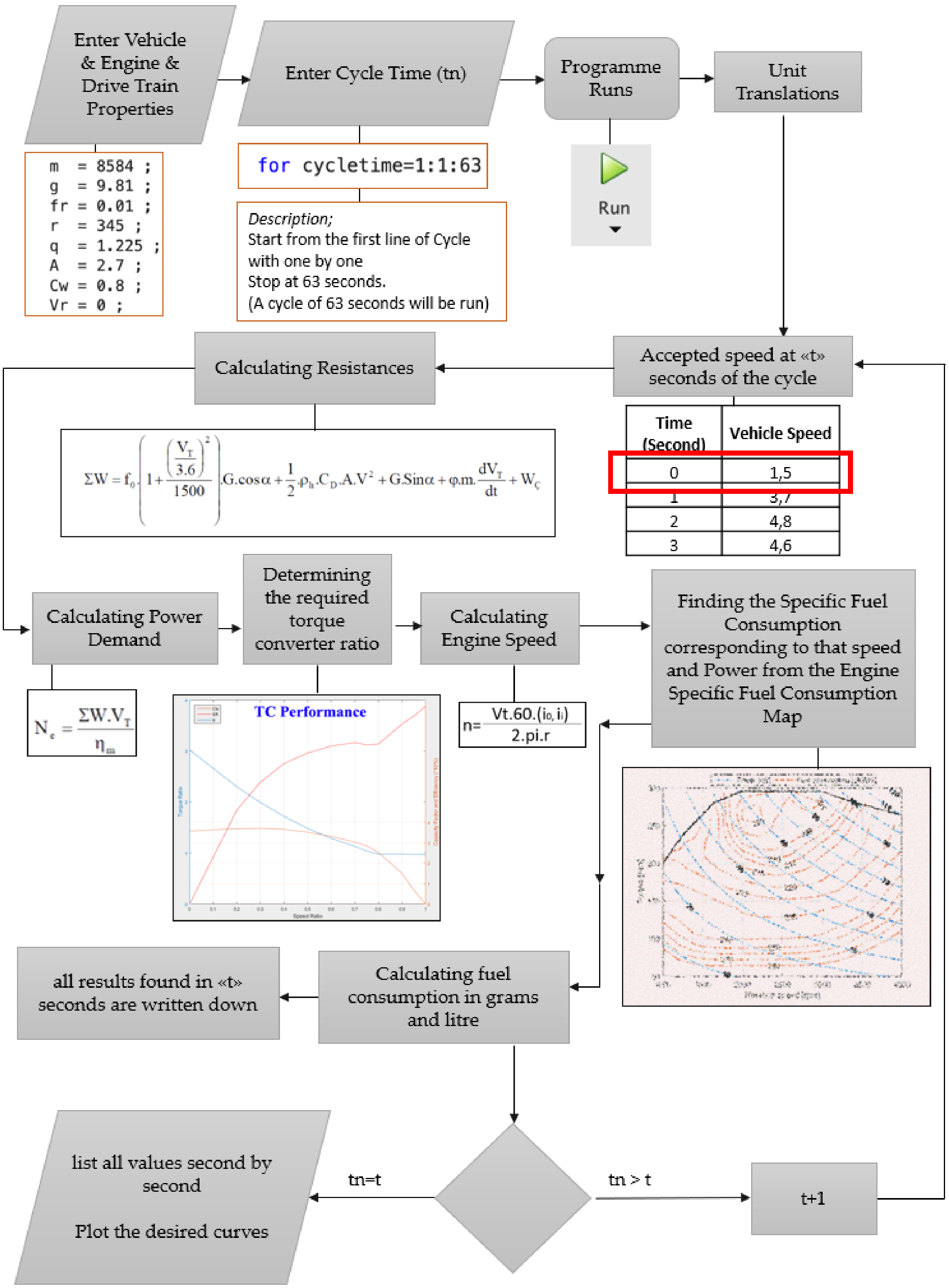


Figure 8: Visual Expression of the Algorithm and Sampling with Input Values

3. Results

When the detailed vehicle, engine, transmission and drivetrain information is written into the algorithm and 63 seconds of the VDI fuel consumption cycle is run, fuel consumption values that are very close to reality are obtained.

As shown in Figure 9, approximately 0.085 litres of fuel was consumed in the 63-second cycle. This fuel consumption will be verified in a test, but is nevertheless very close to the catalogue values of comparable trucks according to VDI 2198.

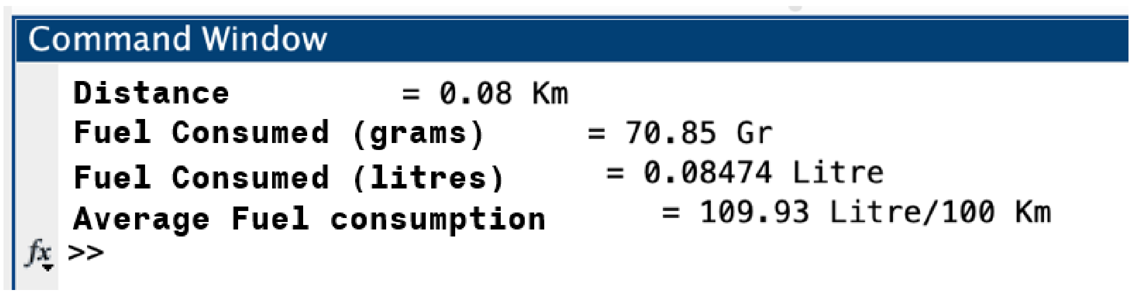


Figure 9: Preliminary Outputs of the Run Cycle

In this analysis, engine speed, power, vehicle speed and fuel consumption graphs were plotted as a function of time. These graphs are shown in detail in figure'10. All of these graphs, especially the average fuel consumption, should be verified with test data.

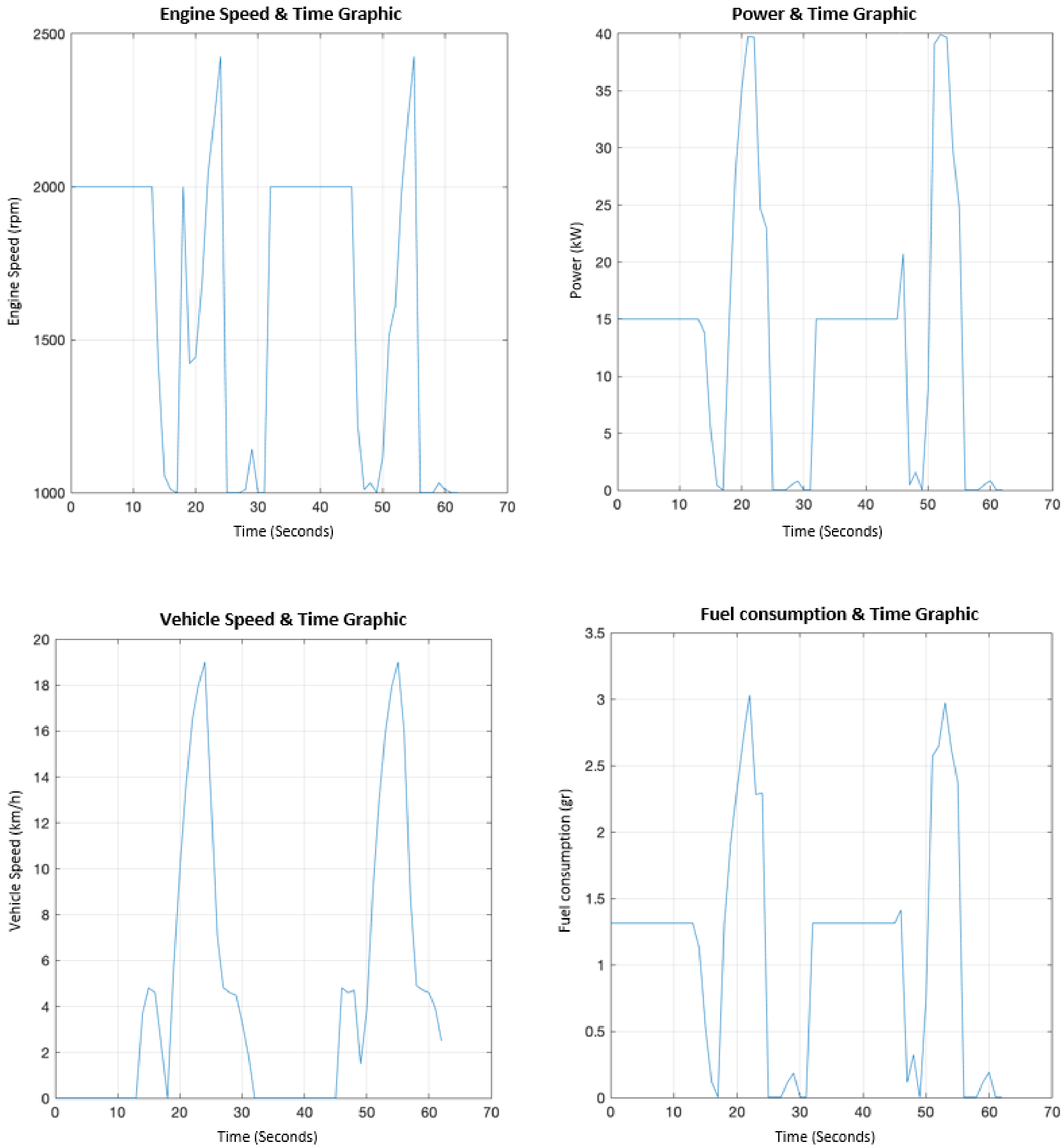


Figure 10: Preliminary Outputs of the Run Cycle

4. Discussion and Conclusion

When the results of the algorithm are analysed, reasonable results are seen. These results should be verified by testing and the differences between the algorithm and the actual test results should be analysed.

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