Implementation of Automatic Lift Axle System for Trucks with Mechanical Suspension

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Abstract

The aim of an automatic lift axle auto-drop system is to drop the appropriate liftable axle of a truck automatically based on the loading condition, instead of being manually controlled by the driver. In this paper, addition to previous studies, experimental implementation of an AutoDrop system to a truck suspended with compensating arm type mechanical suspension is told. Weight estimation for compensating arm type suspension has challenge because of articulation working and huge hysteresis characteristic. An approach is brought and analyzed for weight estimation for the axles with compensating arm using height sensors resulting higher accuracy. An improved algorithm is developed and lift axle system becomes automatized to satisfy the rules mentioned in EU Directive 1230/2012 EEC. An algorithm is achieved by Coding and implementing the software using Electronic Control Unit mounted in Cab.

Key words: Autodrop, Axle Load, Compensating Arm, Mechanical Suspension

1. Introduction

In Turkey and all over the world, highways share most of the transportation load. Highways are expensive investments that must be protected. Commercial vehicles transporting heavy load are an important contributor to the deterioration of the pavement of a highway. Overloading these vehicles leads to the application of excessive pressure per unit area of the road and eventual pavement damage. In order to restore the damage caused by overweight trucks, huge capital investments are needed to upgrade and rehabilitate the existing road network to make it capable to withstand high stresses and tyre pressures caused by heavy wheel loads [1]. There have been many studies performed questioning increased axle load effect on pavement performance, service life and maintenance costs. According to study performed by H.M.A. Salem [2], the maximum allowable axle load should not exceed 11 tons during summer season and should not exceed 14 tons during winter, yet more single axle loads greater than 14 tons should not be allowed even with penalties because it will cause a quick deterioration to the pavement, especially during summer. Additionally, by allowing the axle loads to be increased from 10 to 13 tones, the pavements will last to only one half of its design life compared to the 10 tons axle while study performed by S. Hatipoğlu [3] in Turkey indicates that lowering the legal weight limit than can be supported by a single axle from 13 tons to 11.5 tons results in a corresponding increase in the durability of the highway by up to 32%. One of the factors for overloaded axle is liftable axles by

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transferring axle load to the other axles when lifted position for laden trucks.

The main purpose of the axle-lift device is to raise the axle in order to reduce fuel consumption, tire wear and easier take off on slippery surfaces while the vehicle is not fully loaded. In 2016, the lift axle dropping system is expected to be a legal obligation for heavy commercial trucks in Turkey. The aim of an automatic lift axle auto-drop system is to drop the appropriate axle(s) automatically based on the loading condition, instead of being manually controlled by the driver. According to EU Directive 1230/2012 EEC Mass and Dimensions Policy, the manufacturer must ensure that under all driving conditions, the mass corresponding to each axle or axle groups must be within permissible limits except when taking off the slippery surfaces. There are a couple of systems that satisfy all the obligatory rules on air suspension mounted axles however there is not a feasible system implemented on mechanically suspended trucks with tag axle around the world. In Europe where 1230/2012 EEC is already legislated, all retractable axle fitted vehicles are equipped with air suspension systems. However in Turkey, heavy commercial trucks that have mechanical suspension systems are quite popular. Therefore, the aim of the project is to construct a control mechanism that senses the axle loads and lowers the retractable axle automatically if the nearest axle or axle groups exceed the limits for mechanically suspended trucks with compensating arm type suspension in order to prevent pavement performance of the road to be reduced.

This paper provides an overview of both algorithm and associated simulator developed for heavy commercial truck with mechanical suspension. During the simulations, the condition of the truck's load is used as an input and the automatic lift axle system algorithm decides on the axle(s) that should be dropped. In order to complete a full algorithm, inputs and state-flow chart should be determined. In Section 2 the structure of lift axle mechanisms and boundary diagram for an automatic lift axle system will be introduced. It will be seen that all inputs but axle loads can be derived from vehicle communication line, CAN Bus with J1939 protocol. The algorithm is designed for requirements declared in EU Directive 1230/2012 EEC Masses and Dimensions Policy.

In Section 3 with the advantage of performing co-simulation, the algorithm coded using SIMULINK/Matlab is validated using TruckMaker Virtual Truck Simulation Program by defining a generic truck which is having 8x2S axle configuration with 2 liftable axles and assumption of deriving axle loads from virtual truck model. In Section 4, an approach is brought and analyzed for weight estimation for the axles with compensating arm type suspension using height sensors resulting higher accuracy. In Section 5 by completing the calculation all the inputs including axle loads, the system is implemented a Ford Cargo 3238S truck using PI INNOVO openECU m250 electronic control unit. Proposed algorithm and axle load estimation performances are tested on the vehicle and results are examined.

2. Automatic Lift Axle System

8x2S vehicle is analyzed as it is the worst case in terms of axle configuration. There are two liftable axles indicated in Figure 1. Those axles have different lifting mechanisms but both are controlled same.

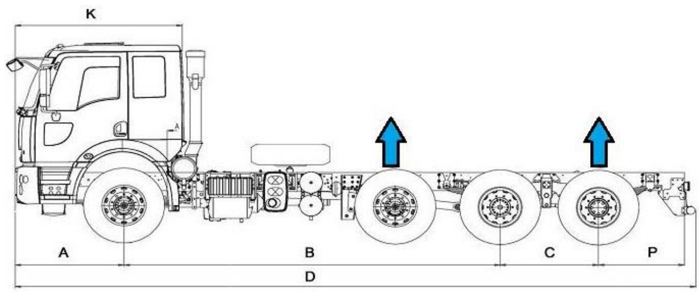

Figure 1. Mechanically suspended truck has 8x2S axle configuration with 2 liftable axles.

Lift axle system comprises of the air compressor, air bags, valves and some mechanical coupling elements. The air compressor provides pressured air to air bags in order to push or pull the axle to position it in either its lifted or lowered condition. Valves control the air flow between the air bags and the air compressor and are also used for exhausting the air from the air bag.

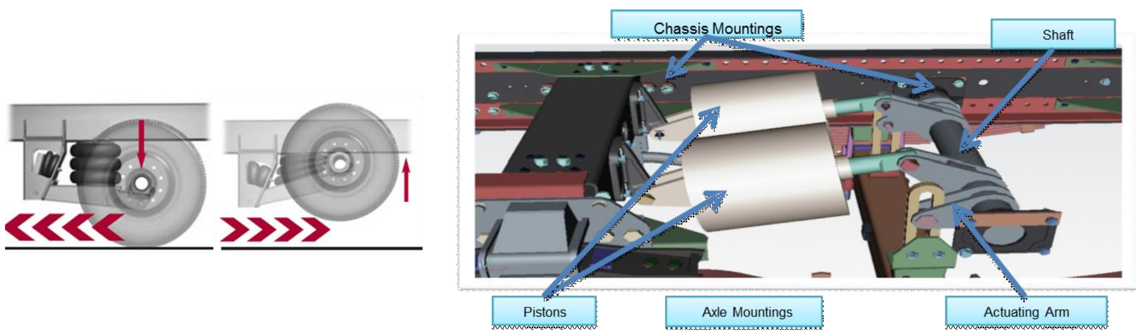

Figure 2. Liftable axle mechanism types

In manual usage solenoid valves are controlled by switches mounted in instrumental panel in cabin. In order to lift/drop the axle, driver pushes corresponding switch and the axle is actuated directly, regardless of vehicle conditions. However in AutoDrop system, brought by this paper, a electronic control unit is used in order to actuate solenoid valves. All environmental components, e.g. switches, lift axle solenoid valves, sensors, are connected to control unit and axles are actuated by running algorithm designed according to regulatory and truck design in ECU.

2.1. System Requirements and Algorithm

Main requirement for AutoDrop system is obviously calculating axle loads. By definition, system must drop the appropriate axle(s) automatically based on the loading condition declared in regulatory as summarized below:

Table 1. Permissible Axle Loads Declared in Masses and Dimensions Policy

Vehicle Condition	1st Axle	2nd Axle	3rd Axle	4th Axle
All axles are on ground	7.1 ton	25.0 tons (sum of rear axle weight)		
2nd axle is lifted	7.1 ton	-	18.0 tons	
2nd and 4th axles are lifted	7.1 ton	-	11.5tons	-

By definition e.g. if 2nd axle is lifted and if rear axle group load exceeds 18.0 tons system will drop nearest axle which is 2nd axle in order to share overload and maintain axle loads under permissible limits and does not allow driver to lift again. Other conditions that do not involve axle loads are also included in regulation in addition to the conditions given above. For instance, once ignition is off, all axles should be lowered in order to prevent tires to be stolen. This feature can be performed by running ECU even if ignition is off. Speed limit is taken into account for functional requirements to provide safety driving by disabling any driver input after 30 kph. Additionally in order to improve emergency brake performance when parking brake is engaged tag axle (4th axle) should be dropped or not allowed to be lifted by driver since wheels should be contacted with road surface. An algorithm satisfies all requirement included is designed with the given I/O table:

Table 2. AutoDrop System Input/Output List

Parameter	Signal	Description	Range
Axle Loads	Analogue	Load input for each axles.	
DR_A2	Digital	2nd axle lift/drop button input	Input
DR_A4	Digital	4th axle lift/drop button input	Input
Ignition	Digital	Ignition is ON OFF information	Input
ECU_A2	Digital	2nd axle lift/drop actuation signal	Output
ECU_A4	Digital	4th axle lift/drop actuation signal	Output
A2_SIG	CAN Tx	2nd axle liftable/not liftable info	Output
A4_SIG	CAN Tx	4th axle liftable/not liftable info	Output
Hold_PSU	Digital	Hold Power Supply Unit even if İgnition is OFF	Output
pbrake	CAN Rx	Parking Brake information	Input
v_speed	CAN Rx	Vehicle Speed information	Input

State-Flow Chart is designed as shown Figure 4. The conditions Q0, Q1 and Q2, represent the different positions where axles can be placed [4]. There are 3 different conditions where axles can be placed in a truck with 8x2S axle configuration, two of which are liftable. State transition conditions are defined according to functional requirements declared in this section. As an addition to previous study [4], each state has its own sub-routines where detailed axle information e.g. axle is being lifted, axle cannot be dropped, axle cannot be lifted are stored. For instance, Q1 indicates that 2nd axle is lifted and 4th axle is dropped. Parameter 'x3' is the transition condition in order to lift 4th axle and defined as below:

- Front axle load should be below 7.1 tons
- Rear group axle load should be below 11.5 tons
- Parking brake should be released
- Vehicle speed should be below 30 kph.
- Ignition should be ON.

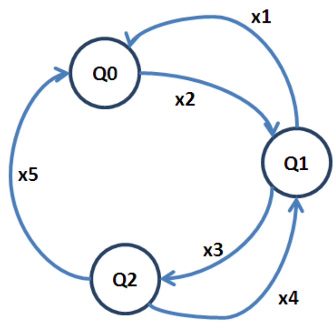

Figure 4. System State-Flow Chart Macro View

3. TruckMaker Simulation

It can be seen from Table 2 that all the inputs but axle loads can be derived directly considering vehicle implementation. Assuming the axle loads can be derived correctly, firstly, designed algorithm should be tested. Prototype vehicle simulation model is constructed for this purpose. TruckMaker as vehicle simulation program is used to model the vehicle, environment, driver maneuver and driving scenarios. SIMULINK is used to implement the algorithm, driver inputs and axle movement command to TruckMaker. TruckMaker and SIMULINK can process co-simulation almost in real-time as simulation speed which is a great advantage because same algorithm codes written in SIMULINK for TruckMaker can be also used for openECU that mounted in truck.

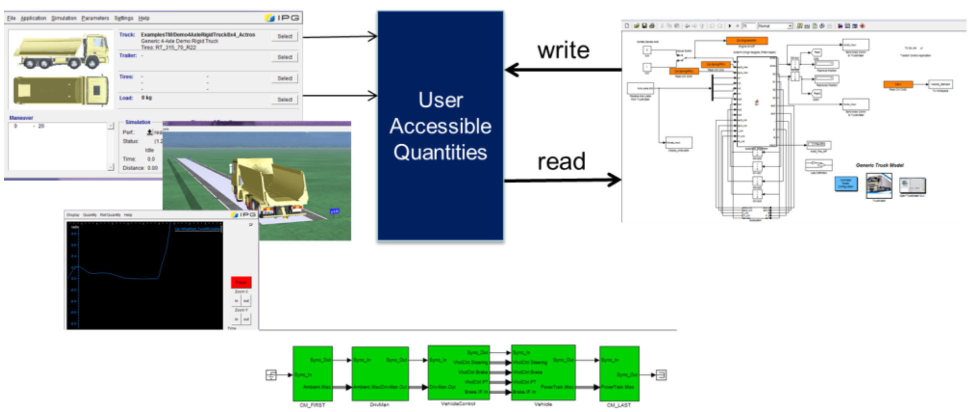

Figure 5. TruckMaker and AutoDrop Software Coded in SIMULINK Co-Simulation

Lift/Drop axle is not defined in TruckMaker as a function. Thus to simulate proper axle movement and axle load distributions, z-axes of tires are altered from software by using discrete integrator.

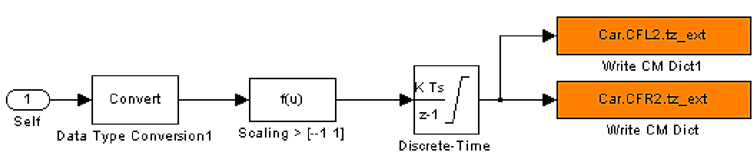

Figure 6. Axle movement commands

System input and outputs are re-organized to TruckMaker parameters:

Table 3. AutoDrop System Input/Output List

Parameter	Signal	Description	Data Name
G1	Read	Front Axle Load	
G2	Read	2nd Axle Load (Self Steer)	Car.SpringFx2.Frc
G3	Read	3rd Axle Load (Drive Axle)	Car.SpringRx.Frc
G4	Read	4th Axle lift/drop button input	Car.SpringRx2.Frc
Brake	Write	Brake Pedal	DM.Brake
Clutch	Write	Clutch Pedal	DM.Clutch
Ignition	Read	Ignition Information	DM.EngineSwitch
Gas	Write	Gas Pedal	DM.Gas
AxlePos	Write	Axle Lift/Drop z-position	Car.CFxx.tz_ext

4. Axle Load Calculation

The basic function of AutoDrop system is to generate appropriate control signal according to axle loads and positions. Thus axle load must be estimated in order to construct an implementable system. This can be achieved by measuring the deflection of springs in other words the distance between axle and chassis arm with using deflection sensors. The set up consisted of an 8x2 self-steer vehicle as a worst case vehicle type, displacement sensors mounted at different positions on each axle, an ECU from Pi Innovo used to test algorithm and data collection, weight pads to understand the corresponding wheel load of the axle as it shown in Figure 7. Mass estimation models are trained for each individual axle that are front-steering axle and the rear group axle called tandem axle unit as drive axle and tag axle interconnected with compensating arm type suspension in order to find correlation between axle load and deflection sensor outputs.

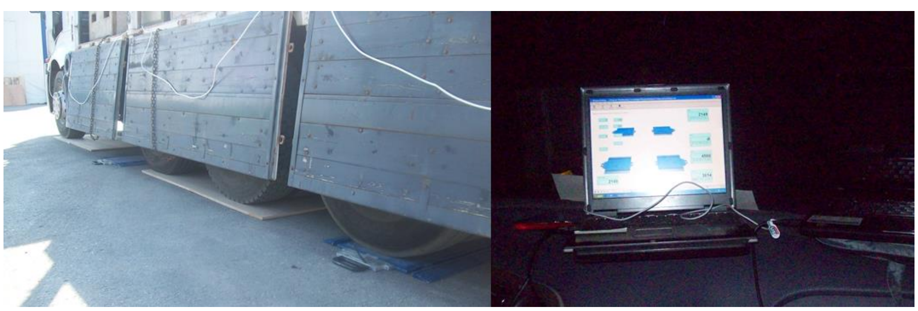

Figure 7. Training Data Collection Tests (Axle Loads and Sensor output)

4.1. Front Axle Suspension Load

Front axle's leaf springs are single mounted springs and have linear load-deflection correlation that has less hysteresis difference between loading and unloading states which is approximately 250 kg. In result, front axle mass estimation model can be extracted using conventional methods with following equation:

$$G_{front} = av_1 + b \quad \textbf{(3.1)}$$

In equation 3.1, v_1 refers to deflection sensor output signal attached to corresponding axle. In order to achieve front axle load G_{front}, a and b is found as 1429 and 64.08 with experimental studies by collection training data and curve fitting. Once the coefficients are found, axle load can be estimated by just using deflection sensor in online-tests.

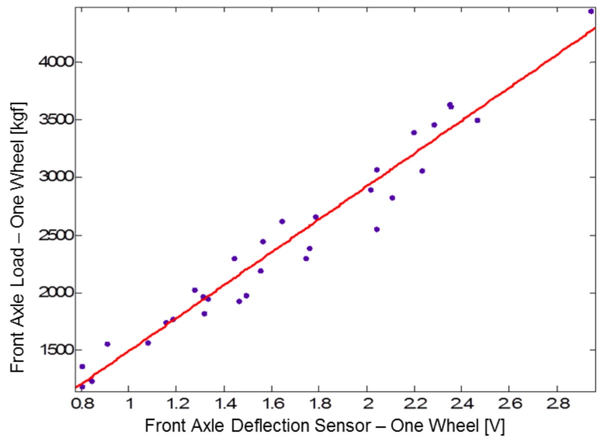

Figure 8. Front Axle Load Linear Function

4.2. Rear Axle Compensating Arm Type Suspension Load

The mechanical suspension mounted trucks generally have interconnected axles on rear axle groups to share the load appropriately on rough roads and the geometry should be adequate in order to balance the load transfer between the axle groups according to the axle capacities. The tandem axle unit as rear group axle's mass estimation model is the challenge here because of drive axle and tag axle that are the elements of tandem axle unit connected each other by a balancer. So their displacements affected each other and correlation between load and deflection extracted accordingly.

$$G_{drive} = fv_3 + gv_4 + h \tag{3.2}$$

In equation 3.2, v_3 and v_4 refer to sensor outputs connected to drive axle and tag axle which are elements of compensating arm type suspension.

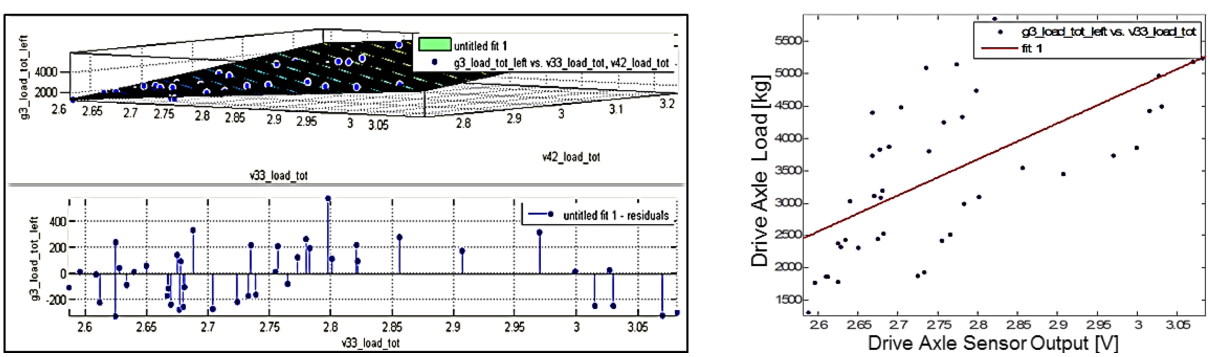

Figure 9. New (left) and conventional (right) methods for Axle Load Estimation

For mass estimation model training especially for tandem axle unit many different vehicle scenarios were tried on each loading condition and nearly 90 different loading conditions in different sequences were used in test specification. The mass distribution characteristics were identified from the combination of vehicle and loading cases. The pre-defined mathematical function parameters are optimized according to collected training data as 4951, 6324 and -28880.

5. Vehicle Implementation

Online axle load calculation is available by entering axle load function parameter to designed software. Beside, algorithm software that satisfies the requirements given in section 2 is validated using TruckMaker. By combining two studies, system becomes implementable to 8x2S truck. AutoDrop system algorithm has been developed for 8x2S prototype test vehicle and run under PI INNOVO m250 ECU module using MATLAB/SIMULINK development platform as software. ECU parameter calibration and embedded program variable monitoring is provided with ATI VISION based on CCP (CAN Calibration Protocol) as shown in Figure 10.

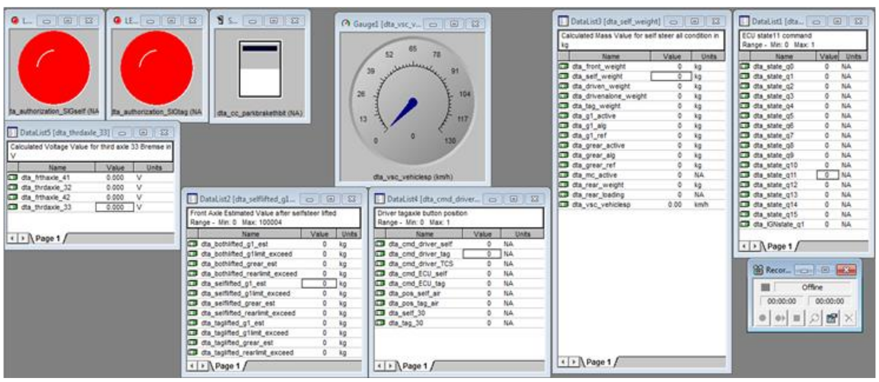

Figure 10. System Parameter Monitoring with ATI VISION by using CCP

Main principle of algorithm is to decide authorization assignment between ECU and driver about lift/drop command on retractable axles. Two indicators in cluster (red circles in Figure 10, refer to Table 2. A2_SIG and A4_SIG) will inform authorization state to driver as an early design. Vehicle is instrumented by electronic control unit, break-out-box and relay circuit. All I/O s are connected to ECU trough break-out-box and solenoid valves are driven by relay circuit.

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Figure 11. Sensor assembly and Electronic Circuit Layout in Cab

6. Results

In this paper an AutoDrop system is introduced and implemented with improved axle load estimation for compensating arm type suspension by defining correlation between the elements of compensating arm type suspension which are drive and tag axles. As shown in Figure 9. , fitted function variation reduced to 489 kg with newly proposed method while in conventional method this value is up to 2 tons. With the proposed load estimation function, mass estimation error is found as 450 kg for front axle. For compensating arm type suspension load estimation performance, to cover worst case, improper 28 loading scenarios has been applied and error is found as 760 kg near design region which, in fact, is permissible axle load limit.

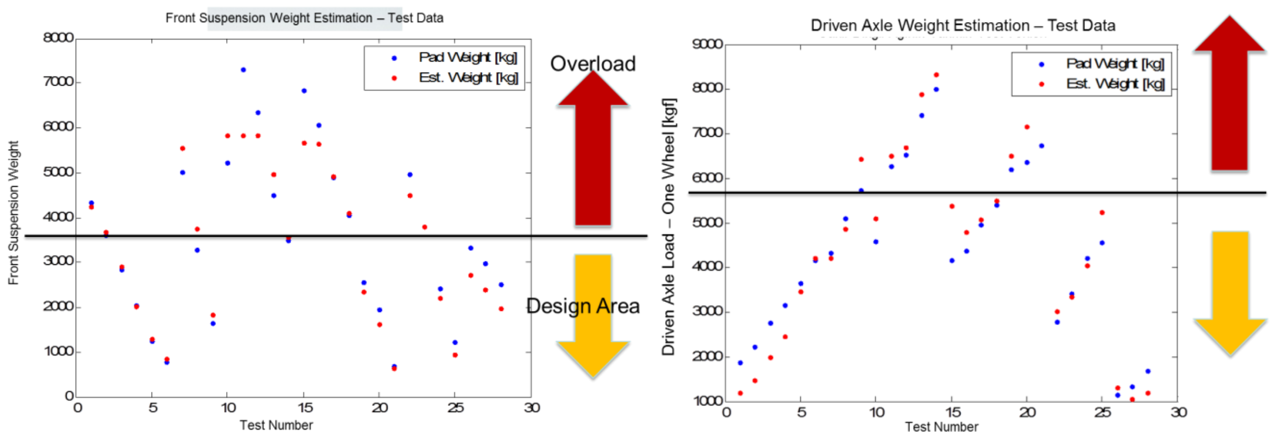

Figure 12. Measurement Error for Both Front Axle (right) and Drive Axle (left)

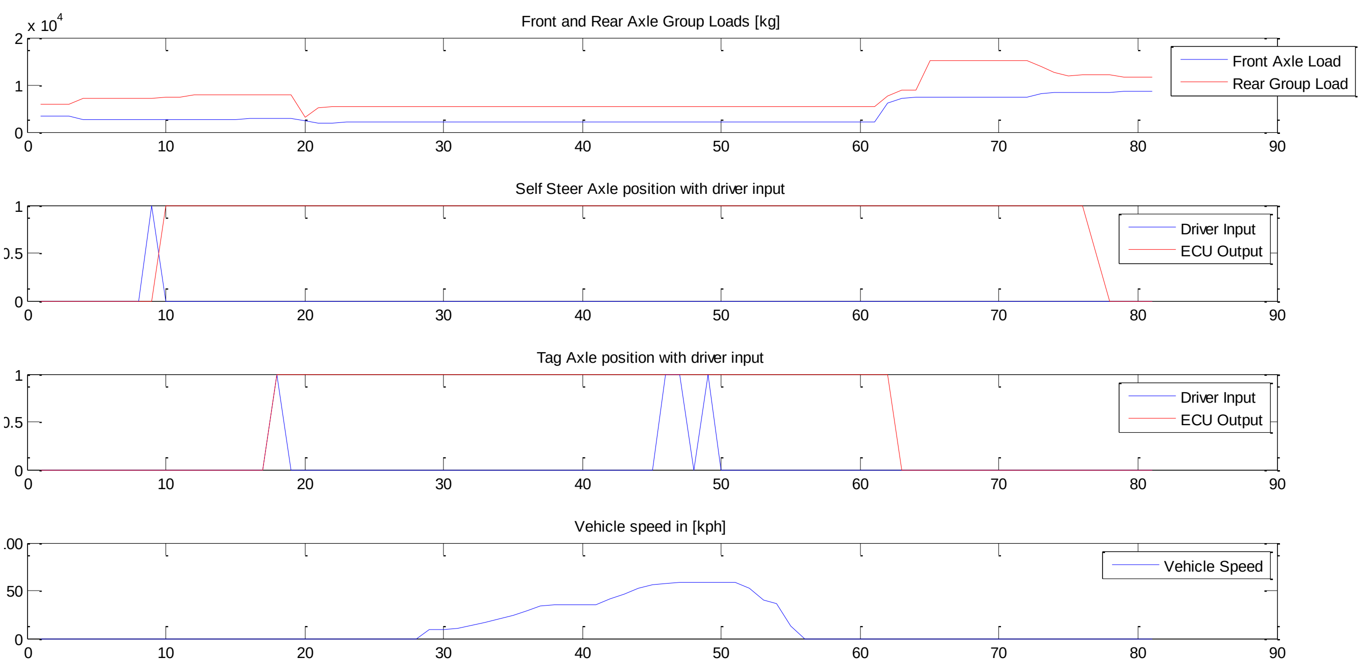

Figure 13. Algorithm Test Scenario

An algorithm satisfies the given requirements, is developed and tested under given scenarios. As it shown in Figure 13 in this scenario, axles are lifted regarding driver demands since the vehicle is unladed. In 45th second, tag axle dropping request from driver is neglected because vehicle speed is over 30 kph. After vehicle is stopped around 60th seconds, vehicle is started to laded and the axles are automatically dropped in order.

Conclusions

An algorithm and improved axle load estimation is studied for AutoDrop system for mechanically suspended trucks. Software is designed using SIMULINK and validated using TruckMaker before vehicle implementation. The aim is to make the system compatible to mechanically suspended trucks, thus a load estimation method is proposed for compensating arm type suspension. Both algorithm and load estimation performance is tested on Ford Cargo 3238S Truck. Results show that there is an improvement on estimations with the method compared to conventional measurement techniques and system is implemented on truck successfully.

Acknowledgements

The authors acknowledge the support of the Ministry of Science, Industry and Commerce of Turkey and the support of Ford Otosan through the SANTEZ Project with code 00905.STZ.2011–1.

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