

# ANALYSIS OF A STOCHASTIC MODEL FOR COORDINATED PLATOONING OF HEAVY-DUTY VEHICLES

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## ABSTRACT

This paper presents a review of theoretical and experimental works related to heavy-duty truck platooning. The platoon formation is characterized by the string of vehicles traveling with small separation distances. Only the first vehicle is driven by a human driver while the followers are assisted by the control system. The main goal of this approach is to reduce fuel consumption and greenhouse gas emissions. This is achieved because the proximity of the vehicles in this configuration provides a more efficient airflow around the set of trucks reducing the overall energy consumption. In addition, the platoon configuration allows the increase of road safety,

Transport capacity, driver comfort and reduces congestion and personnel cost due to the lack of human intervention in the following vehicles. The academic studies related to heavy-duty truck platooning are reviewed according to three research areas: fuel consumption in truck platoons, maintenance of platoon formation

and truck coordination. In this paper, the state of the art in each of these areas is presented, the related publications are categorized according to their focus of contribution and potential future research directions are discussed.

**Keywords:** Platoon, Heavy-duty vehicle, Fuel consumption, Control, Coordination

## 1. INTRODUCTION

In 2010, substantial truck fuel costs measured around \$1100 per family (AT Dynamics SAE, 2014). Except if strategies are taken on to change fundamental patterns, this sum is relied upon to develop impressively during the following twenty years (Cooper, 2014). Carrying out fuel saving advancements could bring down substantial truck fuel utilization by 7-24% and yield a net reserve funds to purchasers. Later on accessibility of fuel is probably going to be undeniably more obliged as existing stores become drained and creation decreases.

Further developing efficiency of the vehicle

will decrease oil reliance and increment energy manageability.

Exact expectation of mileage of rock solid vehicles is vital while considering the pathways to diminish energy utilization from transportation area. A few instruments are as of now utilized to foresee uncompromising. Anyway model presumptions might introduce huge mistakes in expectation. Generally scientists consider device anticipated mileage as the standard efficiency of a motor yet there are different elements, which can fluctuate and will absolutely influence the mileage of the vehicle.

There is generally likelihood that you will observe specific contrast in the real mileage of vehicle and the instrument determined efficiency. Later on, model based reenactment apparatuses will work all the more proficiently as we will know about the error.

Momentum research on rock solid diesel motors is centered around further developing fuel and motor effectiveness. Impending 2017 vehicle eco-friendliness and ozone harming substance outflow guidelines require further upgrades to motor effectiveness from standard MY 2010 HD diesel motors. Vehicle fuel utilization is straightforwardly connected with the motor work, which thus relies upon the street load powers. The street load power

incorporates streamlined drag, erosion and vehicle latency. Streamlined drag is a component of front facing region of the vehicle, vehicle speed and the drag coefficient of the vehicle skeleton.

### **1.1 Objective**

The essential target of this study is to assess the distinctions in efficiency projected via Autonomies and consequences of motor and case dynamometer study. The information used to foresee the fuel utilization that are introduced in this study was gathered at the West Virginia University. In particular, the information was estimated and gathered in a research center on an undercarriage dynamometer.

The optional goal of this study is to portray the fuel guide of an INDIA 2022 MAP consistent hard core diesel motor tentatively and afterward involving those maps in Autonomies to anticipate efficiency. Autonomies help in foreseeing and investigating the eco-friendliness of the vehicle. In the wake of foreseeing the efficiency from the reenactment device, mileage from skeleton and motor dynamometer was contrasted and Autonomies' anticipated efficiency. This will assist in future testing, as we will know about rate contrast in Autonomies' forecast and case and motor dynamometer information ahead of time.

Considering that, the writing survey incorporates an outline of the conversation of the different model based recreation devices, government guidelines for Heavy-obligation vehicles, fuel utilization for HD vehicles and a synopsis of earlier methodologies for precise expectation of fuel utilization.

## **2. LITERATUREREVIEW**

### **2.1 Heavy-duty vehicle fuel consumption**

In September 2011, National Highway Traffic Safety Administration (NHTSA) and Indian Environmental Protection Agency (INDIA) set the first actual joint government hints for the business difficult core cars. These pointers do not become feasible till 2014-2018 so makers have enough opportunity to satisfy the prerequisites of those recommendations. The functions for setting up those recommendations have been to reduce fuel usage of uncompromising diesel automobiles and misfortune of ozone depleting materials on a risky atmospheric deviation (Krupnick and Harrington, 2012). Study from National Research collecting (NRC), assessed new improvements so one can upload to the motor productiveness in 2015-2020 length and the aftereffect of this take a look at showed a decrease in fuel usage by using 7-24% in tough center cars. This concentrate likewise expresses that the expense contribution could be plenty better than the cost

related to 2010 (Krupnick and Harrington, 2012). EPA and NHTSA perceive that streamlined and tire transferring obstruction enhancements to trailers address a important hazard to decrease gasoline usage and GHGs as proven, similarly to other matters, by crafted with the aid of the EPA SmartWay application (NHTSA, 2014) (Federal Register, 2011). EPA's planned SmartWay Transport Partnership application empowers delivery and delivery groups to make movements that reduce gasoline utilization and CO2 via running with the transportation neighborhood location and the shipment location to distinguish low carbon strategies and innovations, and through giving specialized records, financial motivations, and associate acknowledgment to hurry up the reception of these procedures.

## **3. METHODOLOGY**

Through the SmartWay application, EPA has worked in detail with truck makers and truck armadas to foster check technique to assess automobile and part execution in lessening gasoline utilization and has led checking out and has laid out check initiatives to test improvements which can accomplish those decreases. Throughout the maximum recent six years, EPA has created involved enjoy testing the largest tough center vehicles and assessing enhancements in tire and car streamlined execution. In 2010, as according to car makers, around five percent of latest blend rock strong vans will meet the SmartWay execution rules displaying that they

address the apex of cutting-edge tremendous truck decreases in fuel utilization (Federal Register, 2011).

**3.1 Data collection and analysis**

Table 6 and 7 shows the efficiency correlation among suspension statistics and GEM effects for class 8 and sophistication 7 farm truck, one at a time.

Cycle	ProStar Chassis Test(mpg)	GEM(mpg)	GEMerror(%)
ARB Transient	3.51	3.55	-1.14%
65 mph	6.90	6.86	0.58%
55 mph	8.20	8.10	1.22%

Table 6 Fuel economy (miles per gallon) comparison between chassis test data and GEM for class 8 tractor (Indian Environmental Protection Agency, 2014)

Cycle	ProStar Chassis Test(mpg)	GEM(mpg)	GEMerror(%)
ARB Transient	4.10	4.13	-0.73%
65 mph	7.74	7.66	1.03%
55 mph	9.12	9.20	-0.88%

Table eight Comparison among GT-Drive and GEM (Indian Environmental Protection Agency, 2014)

The outcomes in GEM 1.0v edition are shown in MATLAB as soon as all limitations are entered in enter display screen and customer chooses "RUN". Jewel clearly directs undertaking for all of the power cycles at sixty five mph and fifty five mph. Yield contains of each gram CO<sub>2</sub>/ton-mile and gallon 1000/ton-mile results (Indian Environmental Protection Agency, 2014).

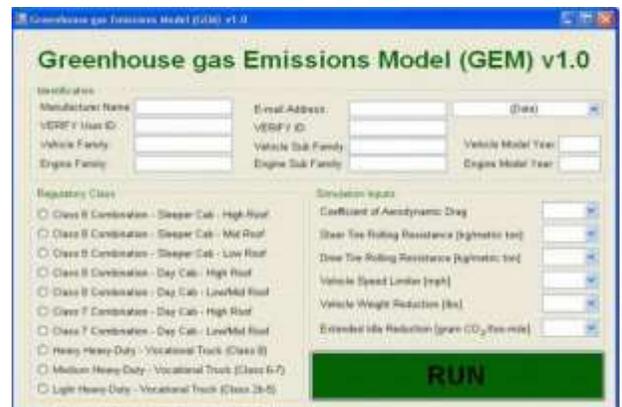


Figure 2 Graphical User Interface of GEM (Indian Environmental Protection Agency, 2014)

Figure 3 suggests the overall version of the series-identical setup which is applied in approval of PSAT. In a pre-transmission function (Karbowski, Sylvain, Kwon, and Rousseau, 2009), the electric device is among the grip and the gearbox. In a submit transmission, the electrical gadget is between the gearbox and the ultimate pressure (or flow case).

Figure three Schematic of the Series-Parallel Configuration (complete-hybrid) (Karbowski,

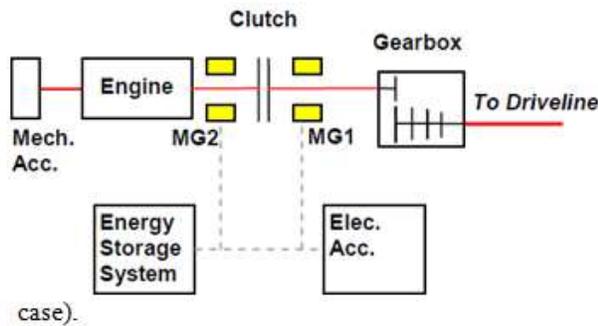
	Cycle	GEM	GT-Drive	Error
Class 8 Combination - Sleeper Cab - High Roof	ARB Transient	3.47	3.53	-1.73%
	65 mph **	6.13	6.19	-0.98%
	55 mph **	7.36	7.38	-0.27%
Class 8 Combination - Sleeper Cab - Mid Roof	ARB Transient	3.6	3.66	-1.67%
	65 mph **	6.75	6.80	-0.74%
	55 mph **	7.96	7.99	-0.38%
Class 8 Combination - Sleeper Cab - Low Roof	ARB Transient	3.63	3.68	-1.94%
	65 mph **	7.31	7.39	-1.09%
	55 mph **	8.52	8.54	-0.23%
Class 8 Combination - Day Cab - High Roof	ARB Transient	3.51	3.57	-1.71%
	65 mph **	6.18	6.24	-0.97%
	55 mph **	7.42	7.44	-0.27%
Class 8 Combination - Day Cab - Low Roof	ARB Transient	3.56	3.72	-4.54%
	65 mph **	7.23	7.40	-2.09%
	55 mph **	8.61	8.63	-0.23%
Class 7 Combination - Day Cab - High Roof	ARB Transient	4.4	4.48	-2.05%
	65 mph **	8.65	8.74	-1.35%
	55 mph **	8.40	8.52	-1.43%
Class 7 Combination - Day Cab - Low Roof	ARB Transient	4.64	4.73	-1.94%
	65 mph **	8.16	8.19	-0.37%
	55 mph **	9.97	10.12	-1.50%
Heavy Heavy-Duty Vocational Vehicle (Class 8)	ARB Transient	3.48	3.47	0.29%
	65 mph **	5.99	5.99	0.00%
	55 mph **	6.81	6.78	0.44%
Medium Heavy-Duty Vocational Vehicle (Class 6-7)	ARB Transient	6.42	6.54	-1.87%
	65 mph **	7.27	7.41	-0.54%
	55 mph **	9.43	9.45	-0.21%
Light Heavy-Duty Vocational Vehicle (Class 26-5)	ARB Transient	8.09	8.15	-0.74%
	65 mph **	8.44	8.48	-0.47%
	55 mph **	10.84	10.90	-0.55%

Delorme, &Rousseau, 2010)

At the factor while those motors have been tried for interstate kind cycles, the gas utilization decrease diminished to single digits in each the cases.

Both those motors along standard vehicle had been reproduced on one-of-a-kind wellknown cycles, both roadway (HHDDT sixty five, HHDDT Cruise, HHDDT High Speed) and temporary/metropolitan (HHDDT Transient, UDDS Truck) utilising PSAT. Figure four suggests the gas utilization of regular and half of breed vans at 50 % load for various cycles.

Figure 5 shows the fuel financial savings of traditional and hybrid trucks at 50 % load depending uponthecycle.



#### 4. EXPERIMENTAL SETUP

The hard core motor with its after-remedy framework became delivered within the test cell. The alternator was additionally not worked on the motor

test cell. While these helpers are relied upon to consume electricity at the same time as getting used (strength usage will be intensely problem to automobile duty cycle), these components aren't ingesting strength at some stage in the motor dynamometer trying out and in this manner are barred from the motor energizing guide.

Then again, the energy usage of some motor related helper components which are essential for motor interest is being expected during the check, and are now certainly protected by the ensuing energizing guides.

Table 12 Engine helpers covered and barred at some point of motor powering map trying out

Included(accountedforin themap)	Excluded(notaccountedforin themap)
Waterpump	Coolingfan
Oil pump	Alternator
Fuelpump	Airconditioningcompressor
	Aircompressor
	Power-steeringpump
	Powertake-off

#### 4.1 Test Cell Integration

The uncompromising Mack MP8 505C motor turned into taken out from a Class 8 farm automobile and added in the check mobile. Since the motor inside the truck interfaces severa vehicle components, it changed into essential for WVU, to accumulate wiring outfit and to associate motor control unit (ECU),

after-treatment ECU and the check mobile manage. Likewise, the motor and after-remedy framework speak with each other and with the car interface through a distinct regulator place employer (CAN) transport, and as a result the motor required precise automobile express limitations, for example, surrounding temperature, car speed and ECU clock to accept by means of the test mobile PC for legitimate running of motor and after-treatment framework. Volvo India 2010 guide upheld the concentrate by using giving the critical CAN messages and systems to finish the coordination of motor within the check cell. With the intricacy of after-remedy joining, it became crucial to assure that the motor had the choice to speak with all units of the after-remedy framework, to prevent motor de-rate and possible non agent open circle gasoline manipulate. The DPF and SCR became utilized within the explicit that they had been while removed from the motor and no healing was performed past to trying out.

#### **4.2 Test Procedure**

The take a look at method become pointed closer to describing the gasoline usage in a tough center diesel motor. The motor instrumentation, checking out approach and demonstrating technique could be clarified in

this phase.

#### **4.3 Engine Instrumentation**

Figure 12 shows the schematic of the instrumentation accomplished on the take a look at motors.

To appraise the electricity streams inside the air, exhaust, coolant, oil pathways, and thermocouples had been introduced on all liquid move pathways to catch the energy circulation in air, coolant and oil pathways. Admission air mass flow price, coolant movement price and motor exhaust flow price were likewise expected. All facts channels wherein recorded at a recurrence of 10 Hz.

The gas circulation estimation for the evaluation was carried out using an AVL gas movement meter. The AVL fuel move meter and molding framework estimates short fuel circulate estimation using the Coriolis rule. The gas circulation meter is in shape for fuel circulate and thickness estimations with a precision of zero.12%. Notwithstanding the AVL fuel move estimation, ECU specific energizing turned into moreover recorded.

Motor convey bend techniques were utilized to quantify the pinnacle force and pinnacle energy bends of the motor as an detail of motor pace. Motor planning is critical to recognise the proposer working of all components of the

motor to deliver the pinnacle pressure and strength determined on the motor tag.

The motor turned into gotten ready to settle the coolant and oil temperatures preceding the approach. WVU test cell programming tracks the motor coolant and oil temperature to determine solidness to start the motor planning approach. Upon adjustment the control programming plays out a very open-choke (WTO) (i.E., 100 percentage choke) clean over the motor pace variety (i.E., from inactive to administered velocity) continuously speeding up at a pace of in 4 rpm/s. Stretches. Three non-stop exams are achieved to approve the closing force and strength bends. These bends are moreover utilized as top limits for the energizing planning system and are required contributions for the motor dynamometer test seat to run FTP and DOE take a look at cycles.

#### **4.5 Fuel Map Developments**

To productively cowl the useful envelope of the motor, unique plan of investigations space filling plans (Gaussian and Latin Hypercube) have been applied to describe the motor gasoline utilization map. Every method gave 25 focuses under the drag bend for a sum of fifty locations. A temporary take a look at which protected the 50 focuses at the same time as following a "irregular walk" pathway between

the focuses turned into directed.

The test caught each regular nation filling on the singular 50 locations and brief powering whilst at the same time transferring beginning with one factor then onto the subsequent. These take a look at cycles additionally proposed the association of focuses to streamline the protected area under the bring bend and to trap the distinction in gasoline usage quotes whilst transferring among the picked 50 places. The take a look at cycles created for the gasoline map development system turned into pointed towards estimating steady filling prices at picked 50 focuses as well as estimating gas usage whilst shifting among the steady nation focuses. This interaction offers an abundance of statistics to put together the model for drifters, inside the occasion that critical contrasts are seen amongst estimated and expected gasoline usage over the FTP cycle.

For the Gaussian becoming interaction, records of the 50 regular state focuses were eliminated from the total cycle information to prepare the gas map forecast mode displayed in discern thirteen. Just steady kingdom records focuses had been applied at the Gaussian becoming cycle, due to restrictions of the JMP programming to address an massive informational series. Subsequently, a subsequent request surface match changed into applied to

### 5. RESULTS

suit the complete informational index that incorporated the whole cycle facts to observe for contrasts in gasoline maps created via the one-of-a-kind method. The resultant 2nd request surface become utilized to populate a 25x25 gasoline utilization map with 625 focuses under the deliver bend. This records force method makes use of the whole informational collection and is relied upon to deliver extra specific effects than a less complicated regular country modes technique.

The next suit records changed into confirmed making use of a FTP take a look at where the anticipated gasoline price for the FTP changed into thought approximately in opposition to the planned gasoline rate at some stage in the FTP. The FTP cycle changed into utilized rather for the confirmation of the version and now not a lot for preparing of the model.

It is to be noticed that not at all like gas utilization, the misfortunes in a motor might be non-direct and hence precision of the misfortune expectation in unique regions of the convey bend might be lost. For instance brake heat proficiency (BTE) in a extensive motor could be streamlined in precise districts of the drag bend to provide best motor execution, and on the off threat that the deliberate statistics did not trap

The effects are illustrative of the checking out led on Mack MP8 motor, led at the case lab and motor dynamometer testing. Body statistics become utilized to run replica on Autonomies to compute efficiency for UDDS and Regional cycles. Mack MP8 2010 gas map applied for this take a look at is displayed in discern 14. Real gasoline circulate price and anticipated gas circulation fee turned into analyzed for 2010 Mack MP8 motor displayed in parent 15.



Figure14Fuel Flow rates forMY2010 MackMP8

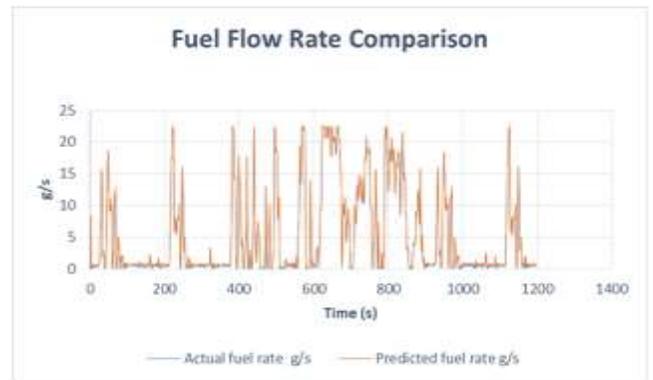


Figure15Actualvs Predicted fuel flow rate comparison

### 5.1 Fuel Map Differences due to different surface its

These fuel maps were made in MATLAB utilizing the bend fitting tool. Various sorts of suits were applied to see the exactness of records considering the R-rectangular well worth. Consistent country statistics turned into applied for the numerous varieties of fits wherein the statistics sources were motor force, motor velocity and fuel circulation rate.

Direct Fit

Direct suit became applied inside the bend becoming tool thinking about consistent nation statistics which protected motor force, motor pace and gas flow charge. R-rectangular and SSE values have been determined to be 1 and 0.0017.

Goodness of fit:	
SSE (Summed square of residuals)	0.0017
R-square:	1

Table 14 Summary of linear fit for Mack MP8

Figure 16 shows the fuel flow rate (gm/sec) point

### 5.2 Summary of UDDS cycle generated from Autonomies Simulation tool

UDDS cycle turned into involved all through this review for the correlation of Autonomies replica effects with skeleton and motor

dynamometer effects. UDDS plan became a purpose for the development of the FTP temporary motor dynamometer cycle.

Table sixteen shows the define that is created from Autonomies reproduction apparatus for UDDS cycle. Rundown suggests that reenactment befell mileage for the UDDS cycle to be four.10 miles/gallon. Vehicle voyaged a distance of 5.32 miles in a span of 1059 seconds, in keeping with Autonomies activity outcomes.

CycleName	Unit	UDDS
Distance Traveled	mile	5.3261
Start Time	seconds	0
End Time	seconds	1059
Fuel Economy	mile/gallon	4.10

Table 16 shows the summary of results generated from Autonomies for UDDS cycle

### 5.3 Comparison of Autonomies simulation with chassis dynamometer data (Regional cycle)

Autonomies reenactment end result and body dynamometer facts become concept approximately using neighborhood cycle, a real cycle. Autonomies reenactment changed into completed making use of car speed (frame information) because the info boundary for the Autonomies apparatus.

A 2010 Mack MP8 gas map become created utilizing the consistent country statistics and was applied in the creation record for Autonomies activity. Figure 20 indicates the changing car pace throughout the local cycle for undercarriage dynamometer trying out. There is an obvious distinction inside the motor pace exam of Autonomies and motor dynamometer in Figure 21. Motor pace if there need to be an prevalence of motor checking out is nearly higher than Autonomies motor velocity. The reason for the distinction in motor speed is Autonomies ran the cycle on a better stuff in assessment with motor dynamometer which introduced about higher motor velocity.

<u>BSFCComparison</u>	<u>%Difference</u>
<u>ComparisonbetweenAutonomiesdataandchassisdata</u>	11.53 %
<u>ComparisonbetweenAutonomiesdataandengine dynamometerdata</u>	8.32 %

Table 17 BSFCcomparison

### 5.4 Comparison of Autonomies to GEM

The GEM rendition 1.Zero, a MATLAB/Simulink primarily based software, which became downloaded from the EPA's site. In this exam, a wellknown 2010 MY turned into chosen for the research.

The truck was reenacted for just ARB Transient cycle to produce gasoline usage records. Table 18 shows the bounds of the vehicle utilized for

GEM duplicate. In the reproduction interaction of GEM, automobile model 12 months, motor model year, coefficient of streamlined drag, force and steer tire moving obstruction had been notion about and utilized as statistics resources.

Table 18 Parameters ofthevehicleused forGEM

<u>GEMVehicleParameter</u>	
<u>VehicleModelYear</u>	2010
<u>EngineModelYear</u>	2010
<u>Coefficientofaerodynamicdrag</u>	0.75
<u>SteerTireRollingResistance(kg/ton)</u>	7.8
<u>DriveTireRollingResistance(kg/ton)</u>	8.2

Pearl accepts a the front going through place of 10.Four m2 for Class eight, sleeper taxi, high rooftop for CdA= 7.8 m2. Table 20 indicates the consequence of reenactment and the results are empowering because the model had the option to interpret gasoline usage sporting events internal 10% blunder

Table 19 Resultof Autonomiesand GEMfuel consumptioncomparison

<u>Cycle</u>	<u>Autonomies Fuelconsum(mpg)</u>	<u>GEMFuel Economy (mpg)</u>	<u>Percentage difference (%)</u>
ARB Transient	4.07	3.81	6.38

## 6. CONCLUSIONS

A reenactment version named Autonomies changed into applied to expect HD vehicle gas utilization and utilizing undercarriage dynamometer data and motor dynamometer facts. Information for MACK MP8 turned into attempted over up to 3 frame dynamometer cycles, and statistics predicted via Autonomies changed into contrasted and frame facts and motor dynamometer records.

It became resolved that after skeleton facts is contrasted and the end result of Autonomies endeavor device, distinction in work done is inner 15 % and gas flow fee is considerably low for example inside 10 %. These charge differences amongst predicted and the expected paintings performed and gas movement fees values are on a similar degree of the fluctuation in expected paintings done and fuel rates among rehased undercarriage and motor dynamometer assessments.

Autonomies expected statistics changed into contrasted and the skeleton data and distinction in work carried out and bsfc ended up being five.Ninety three% and eleven.Fifty three%.

At the point while Autonomies endeavor information become contrasted and motor dynamometer, distinction in paintings

finished, gas circulation fee and bsfc emerged to be 13.21%, 4.Ninety two%, and eight.32% individually.

Autonomies reenactment apparatus turned into examined using gas utilization reproduction facts from a powerful car check system, GEM. The strategy had the option to foresee ARB Transient cycle inner 10% mistake, with an outright blunder of 6.38%. Autonomies can be applied to save undertaking time and to fill capacity holes of information rather than performing reproductions for every achievable software and car magnificence.

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