Analytical Characterization Of Tampering Of Solid Toxic Waste Container On Transit With Installed Weight And Velocity Sensors

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***Abstract*— In this paper, analytical characterization of tampering of solid toxic waste container on transit with installed weight and velocity sensors is presented. In this case, tampering is the removal of part of the solid waste from the solid waste container. Based on certain assumptions, analytical models were developed for the variations in the weight of the solid waste container and the velocity of the vehicle during tampering incidence. The models captured tampering while the vehicle is in motion and also while the vehicle is stationary. In addition, model also captured situation where there removal of the solid waste and replacement of the removed items with another weight. In this case, there is reduction and restoration of the container weight as captured by the sensors. On the other hand, there is tampering without replacement. In this case, the waste container weight continues to reduce as the more solid waste are removed. The variations in the container weight and vehicle velocity in all these tampering cases are modelled analytically and also in Simulink. The Simulink models are used for the simulations. The simulation results in one of the tampering incidence showed that the vehicle acceleration is s lowered to almost 5km/hr2 for 10 minutes. The rolling force on the vehicle rose and fell (between 30 N/minute and 5 N/minute) and deepens during tampering which is majorly the effect of load removal from the toxic waste container. Also, the velocity of the vehicle during the load tampering was not uniform but varied with time in the range of 10 m/minute to 30 m/minute. The variations in the solid waste container weight during load tampering with replacement at stationary point ranged from 5 Kg to 15 Kg. In all, the study showed that through proper sensor data –based modelling, the incidence of solid waste tampering can be effectively detected. This is useful to circumvent the removal of toxic solid waste from the waste container while on transit to the dumpsite.**

Keywords*— *Tampering, Solid Toxic Waste Disposal, Weight Sensors, Deceleration Model, Velocity Sensors

1. INTRODUCTION

Nigeria and many countries across the globe are known for their fossil fuel deposit and explorations activities that have been on for many decades [1,2,3]. The fossil exploration activities generates some wastes which are toxic and hence need to be disposed properly without letting the waste getting into the society where they will pose serious hazards to humans and animals [4,5,6]. In the light of this, best practices are adopted in many oil companies to handle such toxic wastes [7,8].

However, in most case, the task of disposing the toxic waste is outsourced by the oil companies. [9,10]. Though the contract terms requires global best practices to be observed by the waste disposal companies, however, in some case, some of the toxic wastes are stolen and circulated in the society. Such incidences occur mainly during the transportation of the waste from the premises of the oil company to the dumping site where the toxic waste can be properly disposed. In order to address this challenge, in this paper, analytical modelling of tampering monitoring mechanism is presented. The model is used to characterize the key parameters like waste container weight, velocity, drag force among others. The variations in these parameters values are used to determine the likelihood on tampering incidence.

Notably, tampering can come in different forms. There can be tampering when the vehicle conveying the toxic waste container is stationary or while it is in motion. The two scenarios need to be modelled differently. Also, the tampering can be done in such a way that for every weight of waste removed another weight is introduced as a replacement. Also, the tampering can be done without weight replacement. All these scenarios are well captured in the modelling process to ensure that tampering with any combination of the various scenarios can effectively be interpreted by the tamper monitoring system.

2. METHODOLOGY

The model for the velocity and weight of the toxic waste container during load tampering condition is presented [11]. The weight and velocity sensors are installed at strategic points on the vehicle to capture the variations in the waste container weight and vehicle velocity as the tampering incidence occurs.

2.1 Tampering of the toxic waste container

For the toxic waste in the container on transit to be tampered, it is assumed that there is a deceleration of the trailer vehicle conveying the container. In this case, the deceleration model is given in Equation 1.

$$D_{dec} = \frac{\left(V_n - (Aft_R \times M_T)^{\frac{1}{2}}\right)}{dt} \quad (1)$$

where D_{dec} represents the deceleration of the vehicle, V_n represents the velocity of the vehicle at normal condition, Aft_R represents the split angle of the wheel when the deceleration occurs and M_T represents the total mass of the trailer vehicle. At this point, the pattern of the movement of the vehicle can be called ‘rolling’ hence, the force acting on the vehicle while rolling to stop is shown in Equation 2.

$$F_{roll} = D_{dec}\left(1 - e^{\frac{U}{Aft_R}}\right) \quad (2)$$

where F_{roll} represents the rolling process of the trailer vehicle and U is a constant parameter shown in Equation 3.

$$U = Aft_R \ln\left(\frac{Vn}{Aft_R \times dt}\right) \quad (3)$$

The expression for the velocity of the vehicle V_B, where $V_B = H_s\, A_{dec} - \frac{M_e + F_{decc}}{dt}$ can only be applied when the tampering of the toxic waste container occurs during the mobility of the trailer in which case the weight of the container is given as;

$$W_{mob,tamp} = \frac{W_n - w_i}{dt} \quad (4)$$

where W_n represents the weight of the container at normal condition, $W_{mob,tamp}$ represents the weight of the container during tampering which occurs progressively and wi is the weight of the toxic waste removed and replaced (for removal with replacement) or constantly removed without replacement given as;

$$w_i = \ln\frac{F_{roll} * D_{dec}}{dt}$$

Since the trailer would be in motion during tampering, it is assumed that the weight of the container will be reducing periodically with the final weight of the container during tampering and at trailer mobility given as;

$$W_{mob,final} = \sum_{i=0}^{n}(W_{mob,tamp} - w_i) \quad (5)$$

where $W_{mob,final}$ represents the net weight of the container during tampering without replacement and w_i represents the weight of the toxic materials removed which is assumed to be uniformly distributed by the four sensors. The velocity of the vehicle is shown in Equation 6.

$$V_{mob,final} = \frac{D_{dec} \times W_{mob,final}}{dt \times F_{roll}} \quad (6)$$

where $V_{mob,final}$ represents the velocity of the toxic waste container during tampering. The weight of the container waste during tampering but at a stationary point (the vehicle stopped) $W_{sta,tamp}$ is shown in Equation 7.

$$W_{sta,tamp} = \frac{W_n - w_i}{dt} \quad (7)$$

The final weight of the container, $W_{sta,final}$ during tampering is shown in Equation 8.

$$W_{sta,final} = \sum_{i=0}^{n}(W_{sta,tamp} - w_i) \quad (8)$$

Since there is no movement of the vehicle, the velocity in this case is zero;

$$V_{stat,final} = 0 \quad (9)$$

This simply means that the condition in this section outlined the situation of tampering while the trailer is in motion and when the trailed is parked (a stationary point).

The following postulates are adopted in the modelling;

i. The weight of the waste removed while in motion or not is considered uniformed or reducing uniformly (for instance, if 5kg of waste is removed, it is either another 5kg or less that is removed).
ii. The weight of any material used for the replacement of materials taken out must be equal or a little less than the original waste material taken out.

The flow chart for the model is shown in Figure 1. The model is implemented in Simulink.

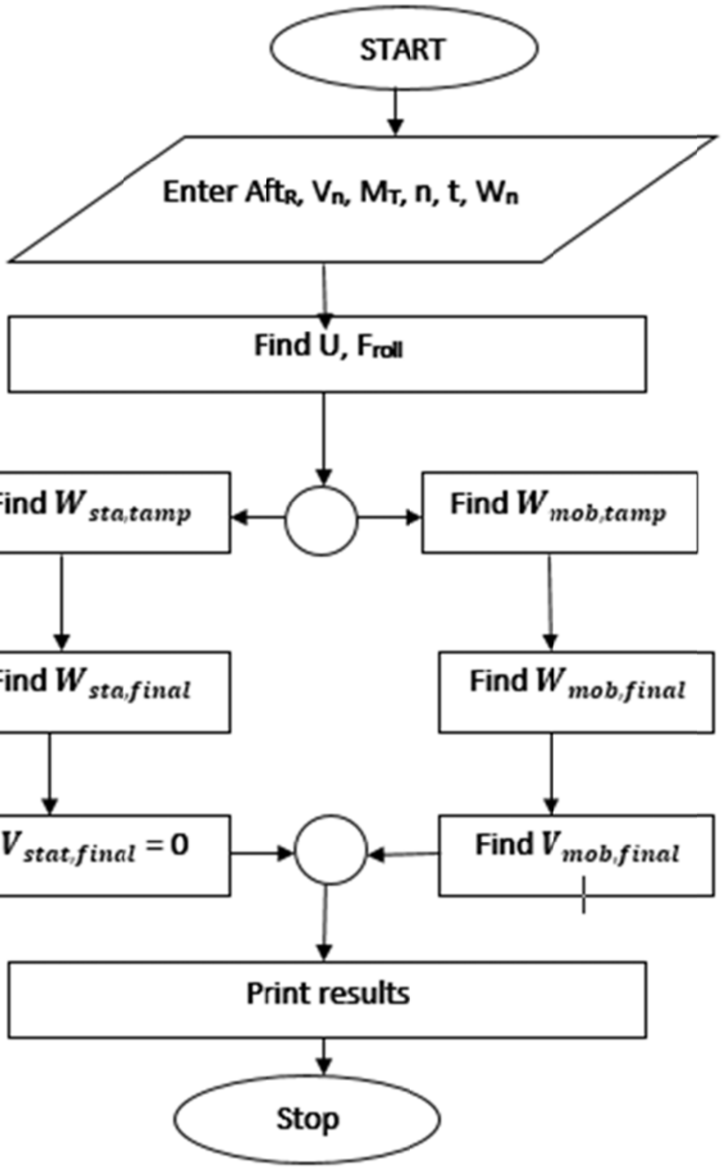

Figure 1 The flow chart of the model for tampering condition

2.2 Simulink model of toxic waste container tampering

The deceleration model in Simulink shown in Equation 1 is shown in Figure 2. The rolling vehicle force shown in Equation 2 is shown in Figure 3. The model for U shown in Equation 3 is shown in Figure 4. The weight of the container during tampering when the truck is in motion as shown in Equation 4 is displayed in Figure 5. The model for the removal and replacement of waste as shown in Equation 5 is s displayed in Figure 6. The Simulink model for the weight of the container during tampering when the truck is not in motion as shown in Equation 5 is shown in Figure 7. The final weight after tampering as shown in Equation 5 is s displayed in Figure 8.

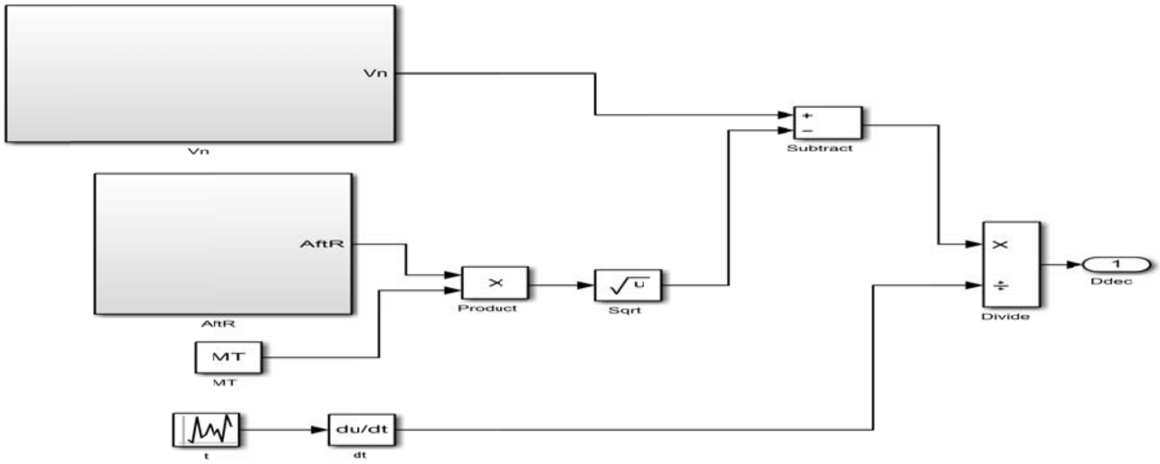

Figure 2; Simulink model for deceleration

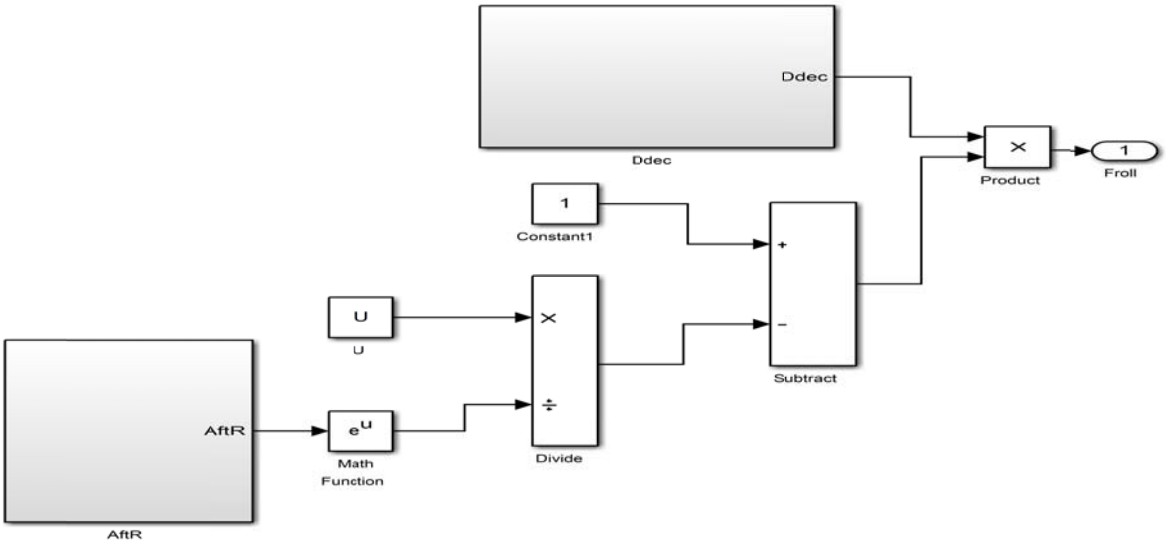

Figure 3; Simulink model of force for rolling vehicle

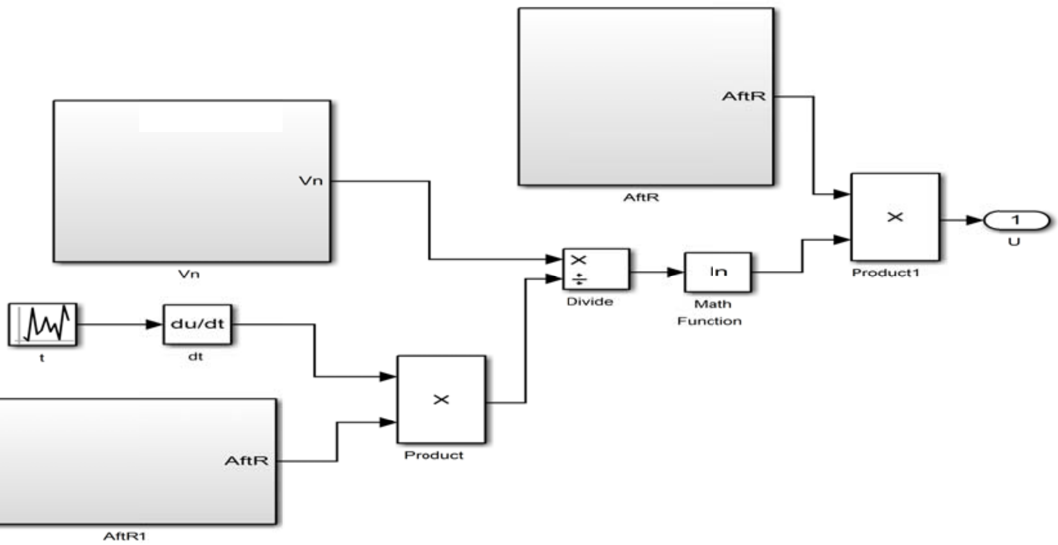

Figure 4; Simulink model for the constant U

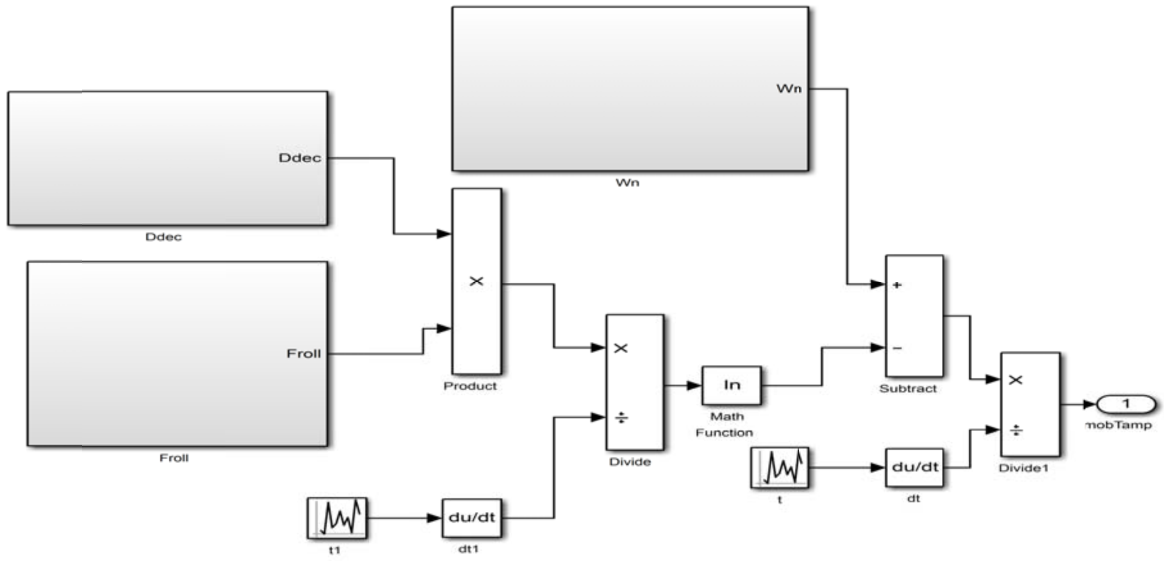

Figure 5; Weight of the container during motion

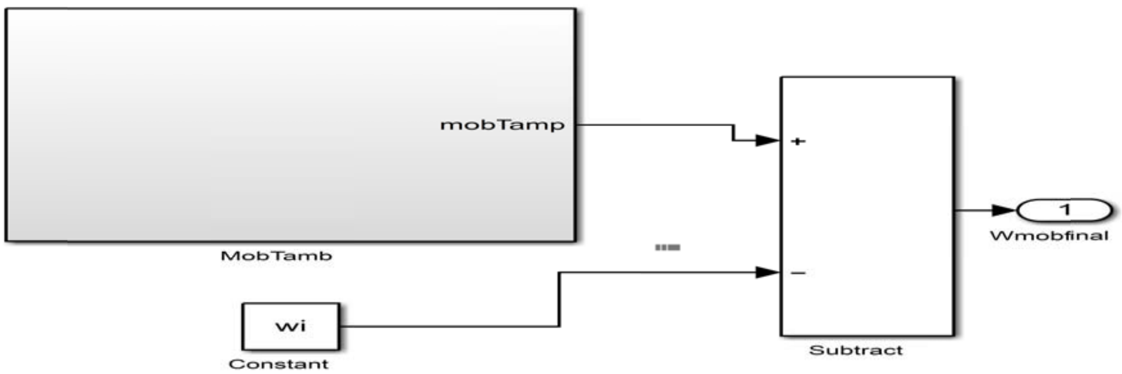

Figure 6; Simulink model for taking and replacement of waste during motion

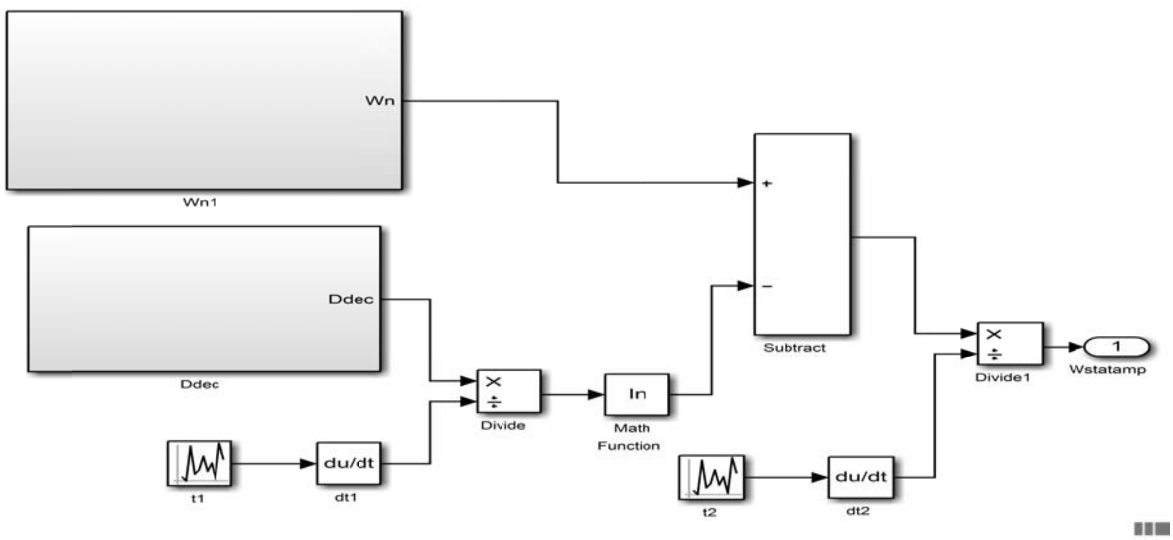

Figure 7; Weight of the container at stationary point

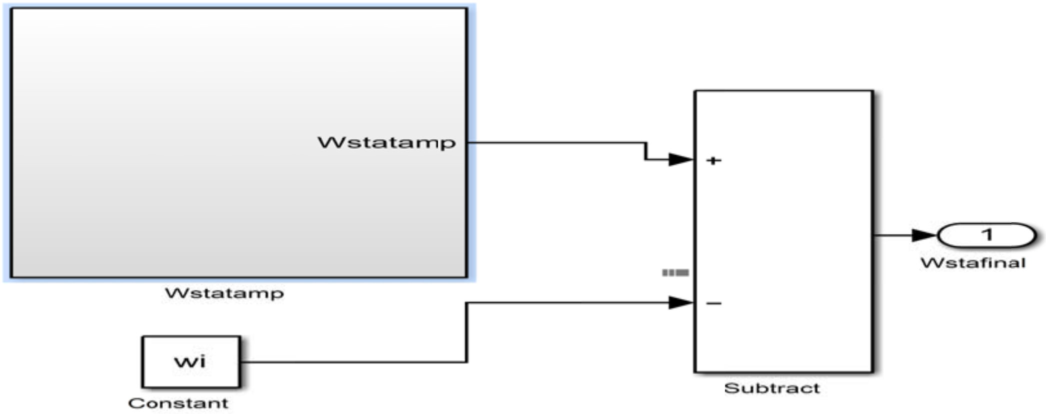

Figure 8;Final weight of the container after tampering at stationary point

3. RESULTS AND DISCUSSION

3.1 The deceleration of the vehicle prior to the load tampering:

The deceleration of the vehicle prior to the load tampering is shown in Figure 9. The vehicles acceleration is s lowered to almost 5km/hr^2 for 10 mins which implied the occurrence of load tampering while the truck is s in motion.

The rolling force of the vehicle during load tampering is shown in Figure 10. The rolling force on the vehicle rises and falls and deepens during tampering which is majorly the effect of load removal from the toxic waste container. The weight of the container during load tampering with load replacement during the truck in mobility is shown in Figure 11.

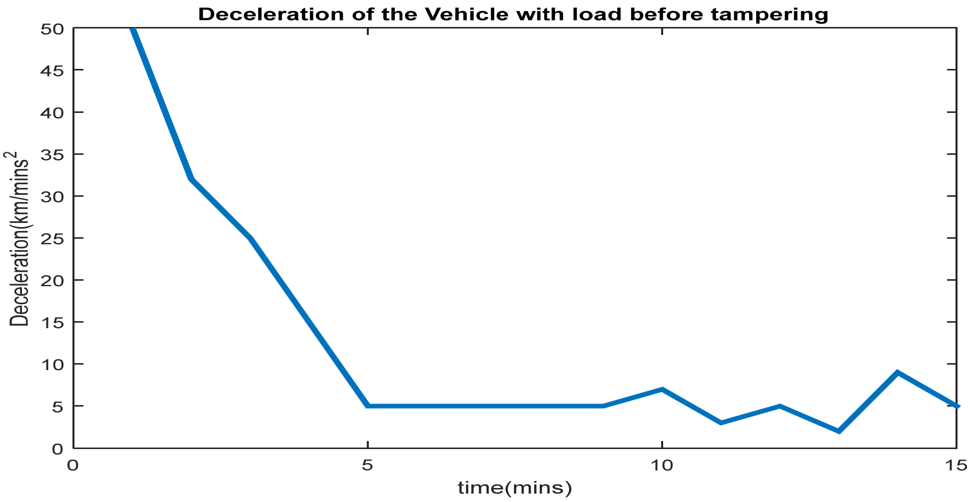

Figure 9; Deceleration of the vehicle before load tampering

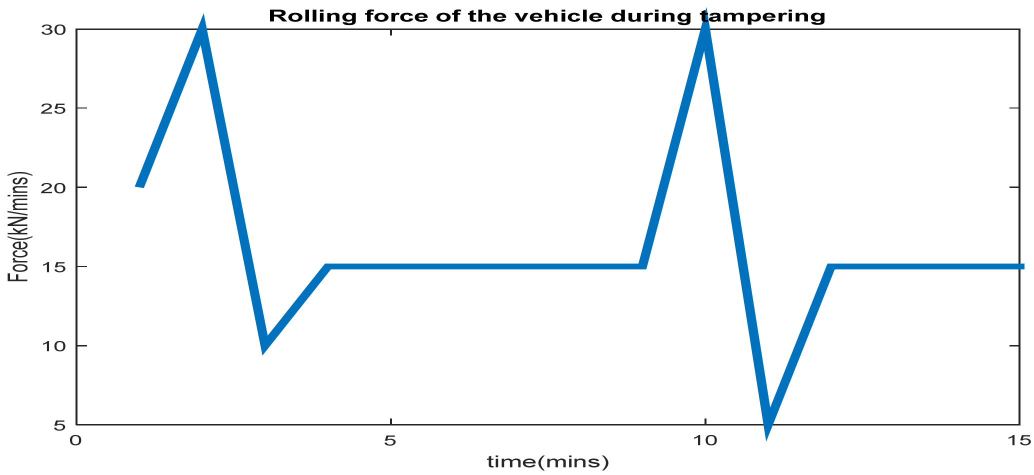

Figure 10; Rolling force of load tampering

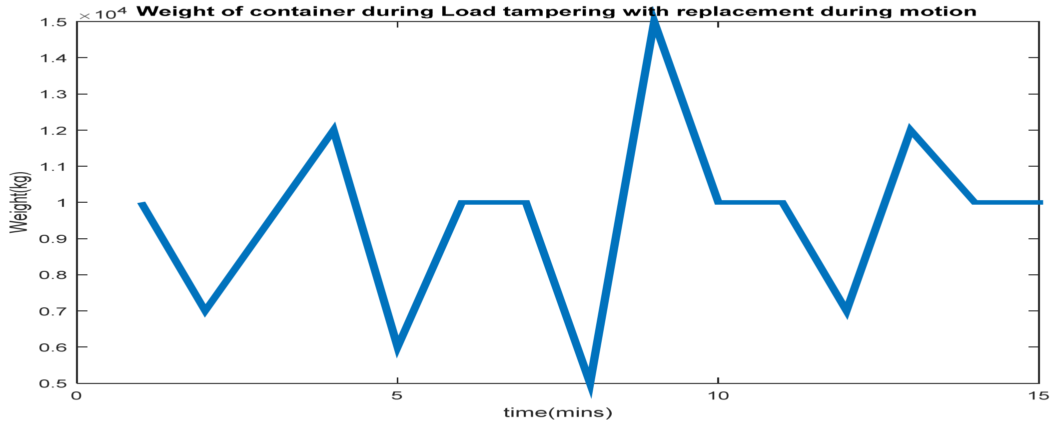

Figure 11; Weight of the container during load tampering with the replacement of the load during the mobility of the truck

The effect of the load removal with replacement as shown in Figure 11 was monitored for 15mins. The graphs shows that the sensors effectively displayed the load removal and replacement. The weight of the container with load removal without replacement is shown in Figure 12.

The load is falling linearly when there is no load replacement as shown in Figure 12. Hence, the load removed without replacement leads to the reduction in weight of the container over time.

The velocity of the vehicle during load tampering is shown in Figure 13. The velocity transmitted by the sensors is the same for all the sensors as shown in Figure 13. It also showed that the velocity during the load tampering is not normal but changes with time but at a range of 30m/mins.

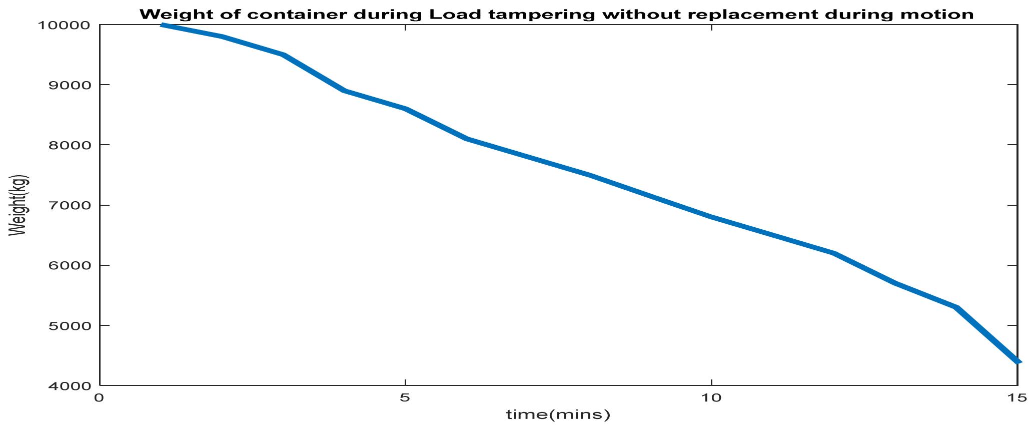

Figure 12; weight of the container with the removal and replacement of the load during motion

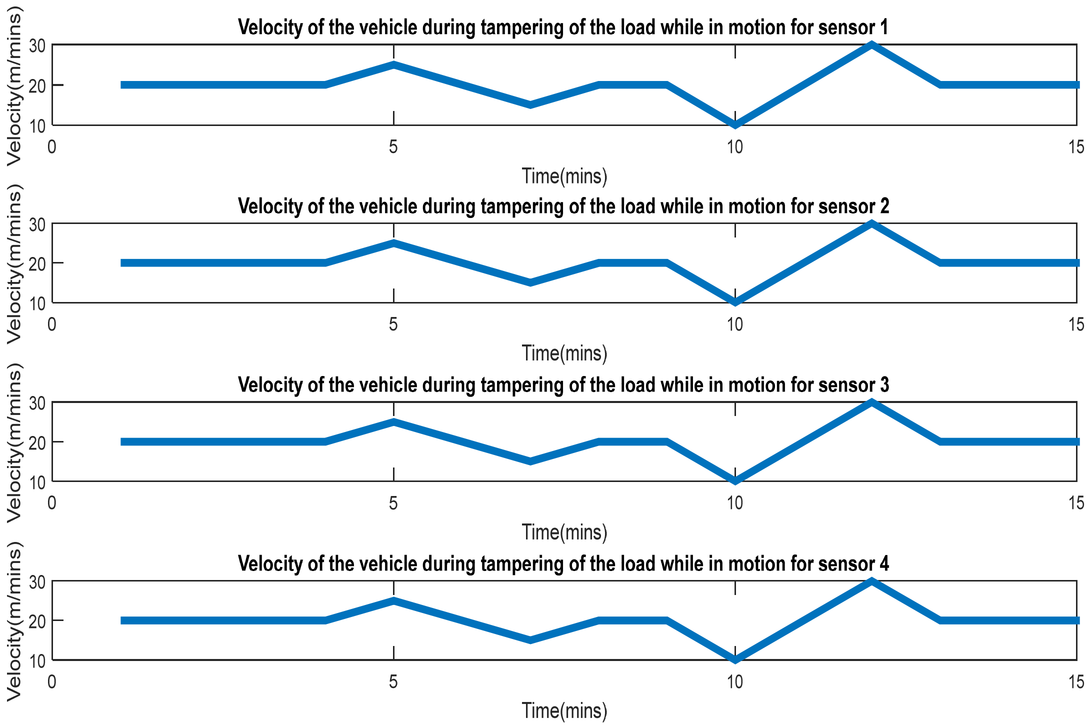

Figure 13; Velocity of the vehicle during load tampering

The load tampering when the vehicle is at static point with and without replacement is shown in Figure 14 and Figure 15 respectively. Both load tampering events were monitored with replacement and without replacement with the truck parked at a point. In this case the velocity is zero. The same effect with the truck in mobility also occurred with the truck in stationary points which points to load tampering. The inertia of the vehicle during tampering is shown in Figure 16. The vehicle inertia is lowered as the load were removed especially the cases where the load were removed without replacement as shown in Figure 16.
The velocity of the vehicle during tampering (especially load tampering with truck mobility) is shown in Figure 17 The velocity from the sensors were the same as shown in Figure 18 for static vehicle which is zero before the removal of the load.

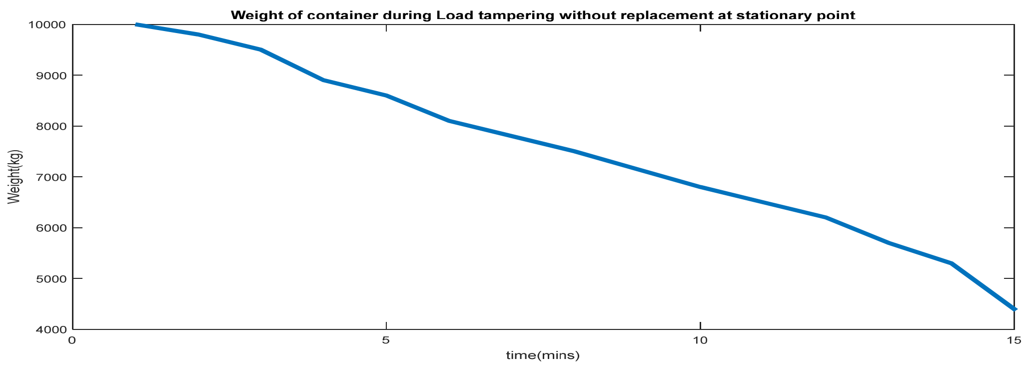

Figure 14; Load tampering with replacement at stationary point

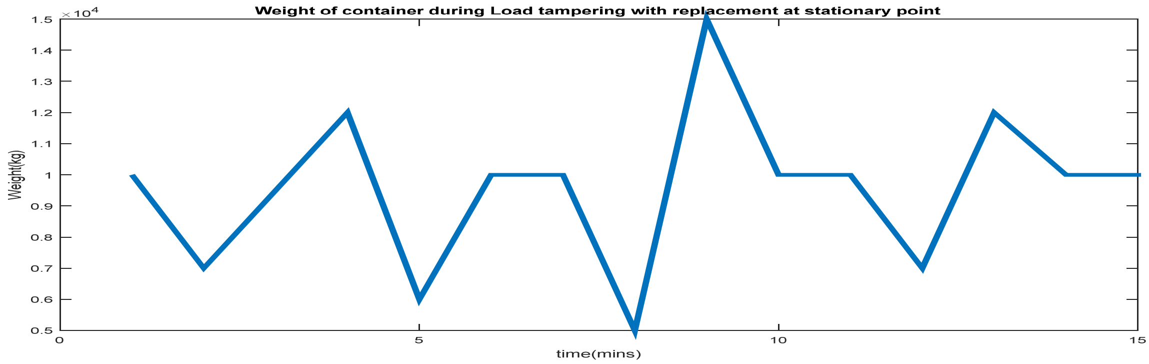

Figure 15; Load tampering with replacement at stationary point

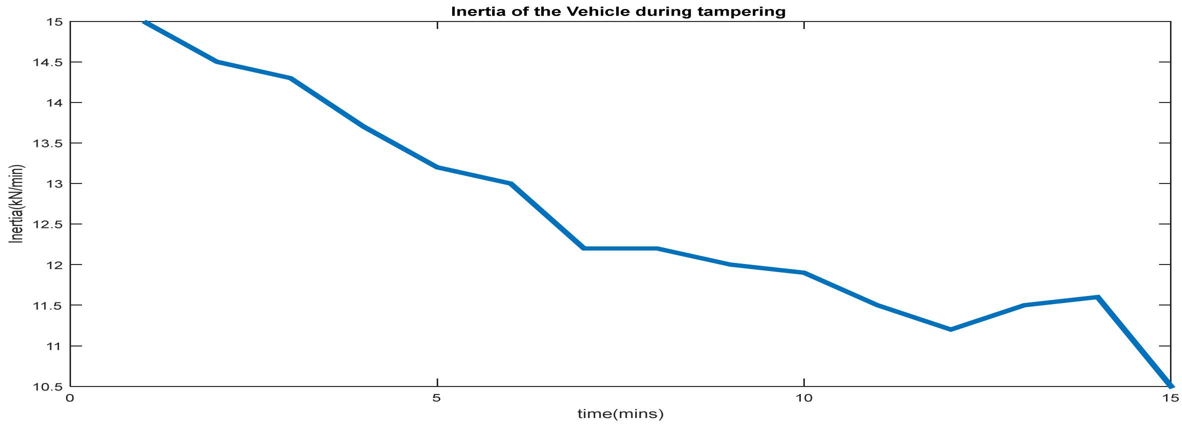

Figure 16; Load inertia of the vehicle during load tampering

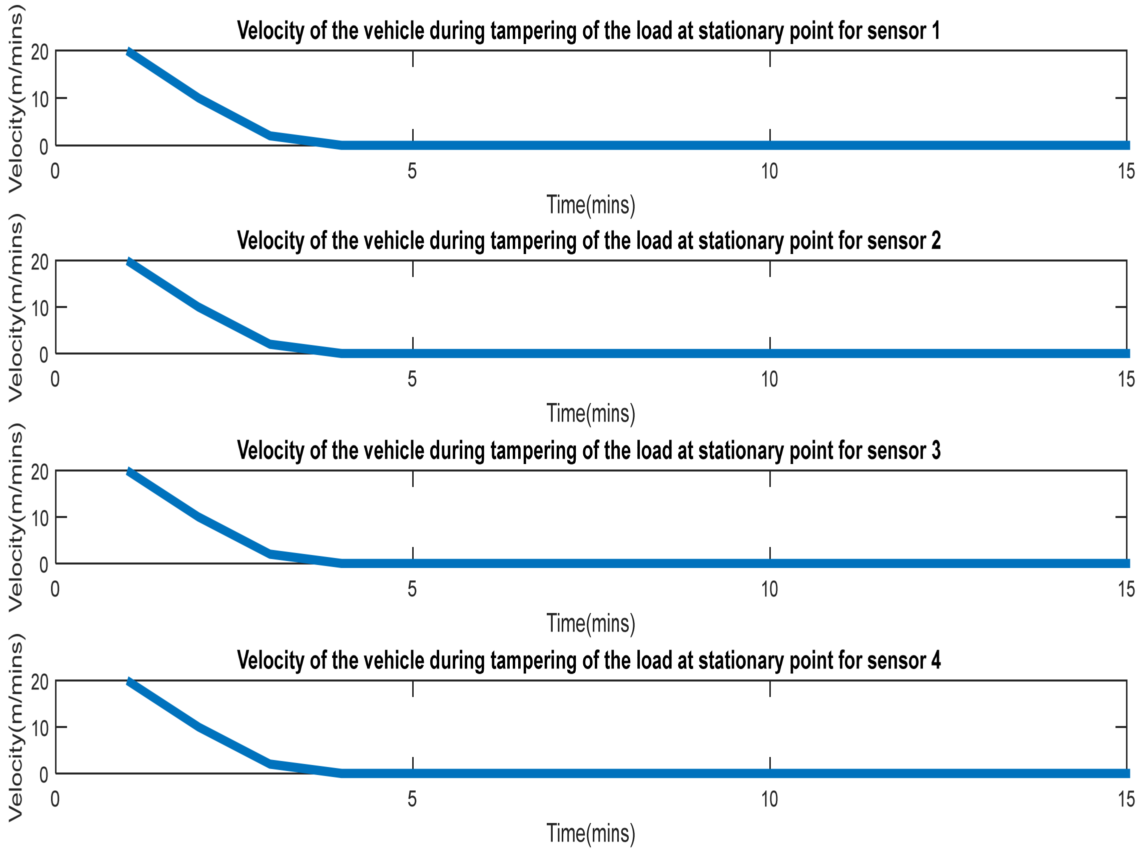

Figure 17; Velocity of the vehicle during tampering

4 CONCLUSION

The tampering of solid waste on transit is modeled to capture the key parameters which will help in timely reporting of incidence of tampering for application in toxic waste disposal management system. The solid waste is contained in a water tight container and conveyed be a vehicle with weight sensors and velocity sensors strategically mounted on selected locations on the vehicle and waste container. The sensor data are used in the modelling to monitor both weight variations and velocity variation dues to tampering. The model also considered tampering with replacement and tampering without load replacement. Furthermore, tampering while the vehicle is in motion is presented as well as tampering while the vehicle is stationary. In all the cases, the weight sensors are able to determine significant variations in the load, and hence, it is possible to correctly predict the incidence of load tampering based on the sensor data values.

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