Novel Method of Determining Braking Distance of Heavy Vehicle using Advanced Simulation Technique

Airul Sharzilia, Rahizar Ramlib, Mohamed Rehan Karimc, Ahmad Saifizulb

Abstract—One of the main causes of fatal vehicle crashes is attributed to the failure of a vehicle to decelerate and stop without hitting the leading vehicle or any other object when applying the emergency brakes due to unforeseen circumstances. Thus, a better understanding of the characteristics of a vehicle’s braking performance is crucial in developing a reliable intelligent collision avoidance system and in creating safety awareness among vehicle drivers. Changes in the vehicle dynamics’ characteristics such as vehicle weight, travel speed and vehicle classification will affect the vehicle’s braking performance and its ability to stop safely in an emergency situation. As such, the aim of this study is to establish a more realistic braking distance model for various classifications of vehicles under various loads and travel speed. These main vehicle parameters which have not been explicitly considered in previous braking distance analytical models are included in the analysis and followed by the proposed regression model. This study uses a kind of complex virtual prototyping software to simulate vehicle dynamics and its braking performance characteristics. The commercial multi-body dynamic simulation was used to generate braking distance data for various heavy vehicle classes under various loads and speed conditions. Using non-linear regression analysis to the simulation results, a mathematical expression has been established. In addition, a graphical user interface (GUI) braking distance calculator was developed based on the regression model. It is envisaged that this calculator would provide a more realistic depiction of the real situation for safety analysis involving heavy vehicles.

Keywords—Braking Distance, Gross Vehicle Weight (GVW), Vehicle Classification, Heavy Vehicle, Road Safety

I. INTRODUCTION

The number of road accidents occurred in developing countries such as Malaysia over the past decade, showed worrying trends. The number of road accidents in Malaysia increased by 59% from 250,429 cases in 2000 to 397,194 cases in 2009 [1]. From this figure, 14% (55,607) of the accidents occurred involved heavy vehicles such as bus, lorry and trailer/tanker [2]. Although the number of registered heavy vehicles hardly makes up 5% of total vehicle registrations, the composition of heavy vehicles in traffic streams may reach 20% of all traffic on the road (depending on locations). Since heavy vehicles vary in types and sizes, the vehicle’s gross vehicle weight (GVW) would vary considerably especially when loaded. The situation would be more serious when truck overloading exists on the roads.

An analysis of traffic accidents indicates that human factor largely contributes to road traffic accidents [3]. Human factor involved in heavy vehicle crashes can be subdivided into various forms. The most common critical error made by drivers, whether they are truck drivers or other involved drivers, appears to be misjudgement of the safe distance gap, which is due to drivers following too closely to the leading vehicle and are over confident in their ability to stop the truck before it crashes [4]. Most drivers consider themselves above average in terms of driving skill. A number of studies conducted in various countries around the world demonstrate that up to 90% of drivers think they are an above average, low-risk driver [5]. For that reason, drivers believe they can travel above the speed limit and not place themselves at high risk.

Vehicle weight is one of the essential parameters in vehicle design study that can affect vehicle driving, braking and handling performance characteristics [6] and most of the time, vehicle dynamics influence the drivers’ behaviour when controlling their vehicles [7]. The study by Saifizul et. al. [8, 9] has shown that the GVW for heavy vehicles has a direct influence on speed whether the vehicle travels in a vehicle following situation or in free flow condition.

Issue in Current Theoretical Formulation and Software Calculator for Braking Distance

Braking distance (BD) is the distance taken for a vehicle to stop from a specific speed without considering the driver’s reaction time. The ability of a vehicle to achieve short braking distance under variables of speed and load is an essential aspect of heavy vehicle (HV) safety. In literature, there were several theoretical formulation and software calculator conventionally used in BD calculation [10, 11, 12]. There are a few theoretical formula that relate the braking distance with vehicle loading such described in reference [13]. Unfortunately, the formula is too complicated and complex for quick calculation. There were few calculator was introduced to calculate the braking distance or stopping distance such as in reference [14]. One observation made regarding the parameter considered in most of these calculators for BD is that, the calculators assume the BD is independent of vehicle mass and
vehicle classification hence only consider the speed of the vehicle. The characteristics of these two important HV parameters are assumed to be the same for all types of vehicles.

The impetus for these studies arises from the intrinsic interest in understanding the factors which influence the BD of HV, from the fact that there was no detail investigation that relates the BD as a function of GVW and vehicle classification. This study has a twofold objective. The first objective is to establish the regression model of the BD which incorporates the GVW and vehicle classification. The second objective is to develop a user friendly graphical user interface (GUI) braking distance calculator. This calculator is designed to give an accurate projection of heavy vehicle braking distance based on regression model from the first objective.

II. METHODOLOGY

The brake performance of vehicles can be analysed in several ways. This can be done through an actual experimental method or through advanced computer simulation. Obviously, the process of building and instrumenting the prototype for actual experimental testing involves significant engineering time and expenses. With the evolution of computer science, computer simulation offers a better alternative to understand physical problems with the capability to emulate extreme conditions and complex engineering analysis. These techniques are often used as an alternative to very costly experimental methods. In this study, MSC.ADAMS software was used to generate BD data for two to four axle single unit truck (SUT) under various GVW and speed conditions.

There are three main steps involved in obtaining the BD data from MSC.ADAMS/Truck which are (a) Virtual Vehicle Modelling, (b) Simulation and (c) Data generation and interpretation. Since the aim of the study is to develop a model that can reflect an actual two to four axle BD situation, it is important to develop a more realistic SUT models. Thus, in this study, the vehicle model and its specification for SUT 2-axle, 3-axle and 4-axle have been developed in accordance to vehicle class available on the Malaysian roads. All of these SUTs will be reconfigured according to the existing SUTs’ parameters.

Simulation was carried out under the assumption that the vehicle has reached a steady state condition and maintains constant forward velocity before the brakes are applied at 285N. The braking analysis and tire properties to run this simulation are shown in Table 1 and Table 2. Furthermore, air drum brake and parabolic leaf spring suspension are used for the heavy vehicle subsystems which are typically used in Malaysia. For this study, a straight and flat road profile is employed whereby differences in road materials and stiffness are not significant.

As stated in the objectives for this study, GVW is the crucial element for this simulation. The lump mass added in storage compartment will be assigned with different mass (5000Kg interval) for each simulation. The GVW is calculated when appropriate loading is assigned for the heavy vehicle. The whole event is conducted under constant forward velocity starting from 40km/h with 10km/h intervals until 100km/h. The entire simulations at the selected velocities are repeated for different GVWs. This is followed by simulations for the different vehicle types i.e. 3-axle SUT and 4-axle SUT.

III. RESULT AND DISCUSSION

In this paper, numerical data were generated as described in previous section. A total of 232 data were generated throughout the simulations. The HV simulation data were grouped according to GVW, vehicle classification, and speed for analysis and line graph were plotted as shown in Figure 1.
Based on plots in Figure 1, a BD regression model for every category of heavy vehicle can be proposed. The proposed model incorporating GVWs and travel speeds of HVs can be expressed as follows:

\[ BD_t = aw + b \]  

Where \( BD_t \) is a braking distance for HV in meter, \( w \) is GVW and \( v \) is speed. The first regression calculation was done to determine coefficients of the regression lines, \( a \) and \( b \) in Equation (1) for various speed. The value of these coefficients and coefficients of determination, \( R^2 \), for all cases are described in Table 3. Another regression calculation was done to determine the coefficients of the regression lines, \( C_i \) where \( i=1, 2, 3 \) and 4 in Equation (1) and coefficients of determination, \( R^2 \) for all cases are described in Table IV.

Using Equation (1), the respective values of BD can be determined for the different vehicle types and GVW at various speeds. The proposed model for BD as a function of GVW for different classes of vehicle has been derived as shown in Table 5. Based on this table, a user friendly GUI Braking Distance calculator was developed as shown in Figure 2.
IV. CONCLUSION

This study aims to propose a regression model for braking distance that not only considers speed but also two others important parameters that is gross vehicle weight (GVW) and Vehicle Classification. From this regression model, a novel BD calculator was developed to offer more precise and easy to use for predicting and analysing braking distance.

There are two major outcomes form these studies. First outcome is a development of a new regression model for braking distance that integrates three important factors that is speed, gross vehicle weight and vehicle classification. The second outcome is a development of a new user friendly GUI calculator for braking distance based on the new model.

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REFERENCES