

## **AN APPRAISAL OF SAFETY OF TRACTOR-TRAILER BRAKING SYSTEM**

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### **ABSTRACT**

The tractor-trailer braking system was appraised considering the effect of braking the tractor or trailer alone and also braking the combination of tractor and trailer simultaneously. The study became imperative considering the influx of trailers that are not equipped with the braking system and the danger it poses to the operators and the farm produce. The study employed simple field simulation of the behaviour of each model and further analysis of the system. The result showed that it would be in the best interest of any country importing agricultural trailers to import those equipped with braking system which could be actuated by the hydraulic control of the tractor. This would reduce to the barest minimum dangers associated with operators of tractor-trailer systems, tyres and loss or damage to produce being transported.

**Keywords:** Tractor, Trailer, Simulation

### **1.0 INTRODUCTION**

An agricultural tractor, as defined in ASAE (1989) Standard, is a vehicle designed and advertised to pull, propel and supply power to operate machinery used in agricultural operations. It also supplies power to agricultural implements and farmstead equipment. An agricultural tractor propels itself and provides force in the direction of travel to enable attached soil-engaging and other agricultural implements or equipment perform their intended functions.

An agricultural trailer is a transport machine used in agriculture which, according to its design is suitable and intended for coupling to an agricultural tractor or self propelled machine.

In order to convey farm produce, implements and equipment, the use of trailer (also referred to as wagon) cannot be overemphasized. Trailer provides convenient means of farm transportation when it is coupled to the drawbar of the tractor. At times it goes beyond mere coupling. The trailer could also be stopped when the trailer braking system is actuated through the hydraulic control valve on the tractor. Baker (1972) and ASAE (2004) reported that wheel properties and soil conditions affect tractive performance differently and cause the wheel to behave differently when it is in driving or braking modes.

In order to optimize the operating performance of the tractor, the models predicting the traction performance of a single driven wheel, should be modified to consider the load transfer effect from the tractor-trailer combination when applying brake.

At the National Centre for Agricultural Mechanization (NCAM) where all tractors and equipment imported into Nigeria are evaluated, it has often been observed that some tractors come with expanded shoe brake system which is preferred over those tractors that utilize brake fluid which is susceptible to failure the moment there is problem with the seal in the master cylinder system.

Despite the growing interest in safety of tractor operators, progress in reducing the accident and property loss is slow (Volpe, 1971). It is worth trying to examine our attitudes to safety and danger. Safety is universally desired and by implication, danger is something everyone wants to avoid. Yet the assumption is at best only superficially true and often demonstrably false.

Osetinsky and Shmulevich (2002) reported that the vertical loads on the wheels of a moving vehicle change dynamically during operation due to load transfer. It was affirmed further that the load transfer is the change between the dynamic and static loads acting on the wheel due to external forces which is influenced by soil variation or acceleration/ deceleration of the vehicle.

National Safety Council (1968) reported that risk and life are inseparable. In order to survive, man has acquired, through the ages, instinctive habits and reflexes to protect himself from the more common hazards. To guard operators and other road users from road and highway hazards during transportation of goods from one location to another using tractor-trailer system, it requires deeper knowledge and understanding of the load transfer due to braking ability of the tractor. Theoretical knowledge is not enough, it requires better skill acquisition such that they are not forgotten in times of tension.

Heinrich (1959) defined accident as an unintentional event which has a probability of causing personal injury and/or property damage. When referring to an accident on farm road or highway, it is qualified according to its type or class as reflected in Table 1.

Table 1. Classification of injury and damage to human beings and property

		$A$	$\bar{A}$
$B$	Property damage	Injury $AB$	No Injury $\bar{A}\bar{B}$
$\bar{B}$	No Property damage	$\bar{A}\bar{B}$	$\bar{A}\bar{B}$

Source: Heinrich (1959)

Table 1 introduce a logical symbolism concept the symbols  $\bar{A}\bar{A}$  and  $\bar{B}\bar{B}$  are borrowed Boolean algebra which is basic to symbol can have one of two value only (0 or 1), what is not A is  $\bar{A}$  and what is not B is  $\bar{B}$  (Ward, 1971).

King and Magid (1979) affirmed that 99% of accidents are preventable though any accident could be traced to its causes which can be one or combination of contributory and underlying causes. In operating a tractor-trailer combination, direct cause of a preventable accident could be human error or some unsafe condition which can be mechanical, physical, chemical or environmental. However, the major cause of accident is usually traced to human error or ignorance. Tractor maintenance in Nigeria is poorly conducted; most often a tractor is not maintained until it stops functioning. This is a cost that could have been prevented because most times the preventive maintenance, if not carried out, may lead to human injury or death. Then the cost of the accident becomes more difficult to evaluate. Philosophically, human life and money are on different planes even though compensation has to be paid (King and Magid, 1979).

The hidden costs of farm road and highway accident of a tractor-trailer system cannot be underestimated; thus the need to appraise the tractor-trailer braking system. Overall safety is an important consideration (Mohan and Patel, 1992; Nag and Nag,2004; Tsakalos and Mouolis,2005; Miller and Fragar,2006; Monarca et al.,2009; Myers and Hendricks,2009; Abubakar et al.,2010).

Tractor-trailer system operation is common in Nigeria. Whenever tractor is moving alone, it is easier to control compared to when it is pulling a trailer which is only linked to the tractor via the drawbar hitch point and probably hydraulic system. Most times the trailer is used to carry loads that may be about the same weight as the tractor, thereby making it difficult for the tractor to pull along the trailer. Where it manages to pull the trailer, it may be more difficult to halt or stop the tractor by the operator since the brake design for the tractor has its own limit. Prasad and Meena (1989) conducted research works on the dynamics and stability of the agricultural tractor. However, this study focuses on the determination of the braking performance of tractor-trailer combinations under dynamic loading conditions.

### 1.1 Objective

The aim of this study was to develop model equations to actuate the braking system in a tractor-trailer combination with a view to eliminating accidents to the operator and reduce damage to the produce being conveyed.

### 2.0 Justification

In any farm operation, the slippage increases downhill and skidding increases uphill which invariably affect the timeliness of operation and its associated cost. Tractor safety concerns most farmers because nearly all farms have sloping land and overturning accidents can occur on moderate slopes (Hunter, 1981). It was affirmed further that the number of tractor accidents can be reduced by following three main approaches:

- i Training of tractor drivers;
- ii. Developing safety aids; and
- iii. Designing safer machines for slopes.

Hunter (1981) reported that stability and control losses accounted for two-thirds of all reported tractor overturning accidents. It would definitely be worse if trailer wagon were also involved in such accidents.

## 2 CONCEPT DEVELOPMENT

The analysis was based on the common and simpler conditions encountered in tractor operations thus:

1. Uniform travel in one direction on a smooth level surface;
2. Drawbar load reacting horizontally;

3. Supporting soil reaction on front and rear wheels applied vertically under centres of axles;
4. Horizontal soil reaction is parallel to direction of travel and tangent to low point of wheel rim;
5. The centre of gravity is located at about  $L$  from the rear wheel and at a height of about  $D/2$ , where,  
 $L$  = distance between front and rear wheels;  
 $D$  = Diameter of rear wheel; and
6. The acceleration of tractor is the same as that of trailer ( $a_1 = a_2 = a_3 = f$ )

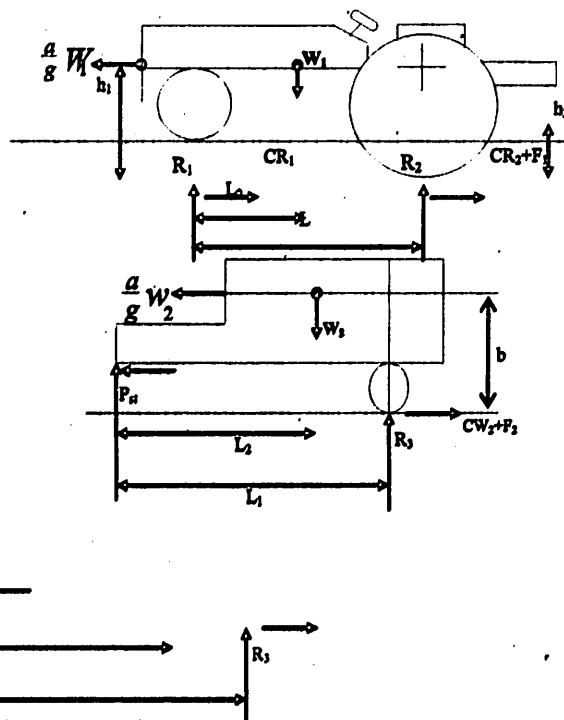


Figure 1. Simplified model of the tractor and trailer system

When the tractor is equipped with braking system  
 Assuming the trailer is not equipped with brake system,  $F_2=0$  and at the point of instability,  $CR_1$  is insignificant 0  
 Considering Horizontal Plane (Static)  
 Taking moment about  $R_3$   $\sum \tau = 0$

$$P_{st}l_1 - W_2(l_1 - l_2) = 0 \quad (1)$$

$$P_{st} = W_2 \frac{(l_1 - l_2)}{l_1} \quad (2)$$

When the tractor alone is equipped with braking facility  $P_{st}$  is not constant, it increases during braking due to additional load transfer. This is based on the assumption that the tractor can withstand the trailer load.

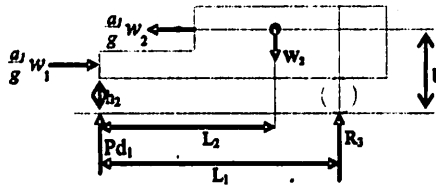


Figure 2. Force reactions when tractor alone is braked on the simplified model of the trailer wagon

Assuming the friction between ground and wheel is negligible. When the tractor alone is braked, the deceleration ( $g$ ) of the trailer would be due to horizontal force transferred through the drawbar

Taking moment about  $R_3 \quad \sum \tau = 0$

Taking moment about  $R_3 \quad \sum \tau = 0$

$$\frac{a_1}{g} W_1 h_2 - \frac{a_2}{g} W_2 b - W_2 (l_1 - l_2) + Pd_1 l_1 = 0$$

$$Pd_1 l_1 = \frac{a_2}{g} W_2 b - \frac{a_1}{g} W_1 h_2 + W_2 (l_1 - l_2)$$

$$Pd_1 = \frac{a_2}{g} \left( \frac{W_2 b - W_1 h_2}{l_1} \right) + \frac{W_2 (l_1 - l_2)}{l_1} \quad (3)$$

When tractor alone is braked, the static load on the drawbar is increased by

$$\frac{a_2}{g} \left( \frac{W_2 b - W_1 h_2}{l_1} \right) \quad (4)$$

When the Trailer alone is equipped with braking system

Taking moment about  $R_3 \quad \sum \tau = 0$

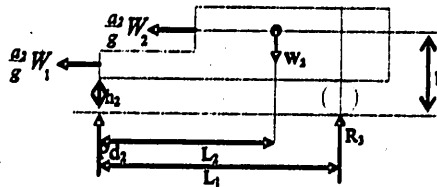


Figure 3. Force reactions when trailer alone is braked on the simplified model of the trailer wagon

$$\frac{a_2}{g} W_1 h_2 + \frac{a_2}{g} W_2 b - P d_2 l_1 + W_2 (l_1 - l_2) = 0 \quad (5)$$

$$P d_2 l_1 = \frac{a_2}{g} (W_1 h_2 + W_2 b) + W_2 (l_1 - l_2)$$

$$P d_2 l_1 = \frac{a_2}{g} \frac{(W_1 h_2 + W_2 b)}{l_1} + \frac{W_2 (l_1 - l_2)}{l_2}$$

Let

$$\frac{W_1}{W_2} = K$$

∴

$$P d_2 = \frac{a_2}{g} \frac{(k h_2 + b)}{l_1} + P_{st} \quad (6)$$

When trailer alone is braked, the static load on the drawbar is increased by

$$\frac{a_2}{g} \left( \frac{k h_2 + b}{l_1} \right)$$

When the tractor and trailer are equipped with braking system

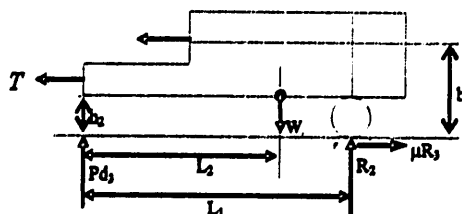


Figure 4. Force reactions when tractor and trailer were braked on the simplified model of the trailer wagon

Taking moment about  $R_3 \curvearrowright = 0$

$$Th_2 + \frac{a_3}{g} W_2 b - Pd_3 l_1 + W_2 (l_1 - l_2) = 0$$

$$Pd_3 l_1 = Th_2 + \frac{a_3}{g} (W_2 b) + W_2 (l_1 - l_2)$$

$$Pd_3 = \frac{Th_2}{l_1} + \left( \frac{a_3}{g} \frac{b}{l_1} \right) W_2 + \frac{W_2 (l_1 - l_2)}{l_1}$$

But  $\Sigma H^+ \rightarrow = 0$

$$-T - \frac{a_3}{g} W_2 + \mu R_3 = 0 \tag{8}$$

Since  $\mu R_3$  is negligible

$$T = \frac{-a_3 W_2}{g}$$

$$Pd_3 = - \left( \frac{a_3 W_2}{g} \frac{h_2}{l_1} \right) + \left( \frac{a_3 b}{g l_1} \right) W_2 + P_{st} \tag{9}$$

$$= \frac{a_3 W_2}{g} (-h_2 + b) + P_{st}$$

$$Pd_3 = - \frac{T}{l_1} (-h_2 + b) + P_{st}$$

$$Pd_3 = \frac{T}{l_1} (h_2 - b) + P_{st} \tag{10}$$

From the above analysis, it could be inferred, that when the tractor and trailer are equipped with separate braking system, the static load on the drawbar is reduced by

$$\frac{T}{l_1} (-h_2 + b)$$

The force required to stop the tractor-trailer system would be low. Also the braking system of the tractor would not be overstressed and as such it would increase the life-span of the tyres and the braking system.

### 3 RESULTS AND DISCUSSION

From the concept analysis and simplified equations developed, the result/discussion was considered from three perspectives as follows:



**i. When tractor alone is braked**

For a tractor-trailer system in which the tractor alone is equipped with braking facility, it is obvious that the stability of the tractor would be maintained only if the load transfer to the tractor is minimal at a level that it will not create instability for the tractor.

This means that the tractor would not only withstand its own weight but also the weight of the trailer. This implies that for a system of this nature (with braking facility on tractor alone) to be safe for an operator to drive, the trailer load during motion must not generate more than the required additional load while applying the brake. If it is more, the load on the trailer will push the tractor beyond what the braking system can support thereby endangering the life of the tractor operator and loss of the farm produce being conveyed

**ii. When trailer alone is braked**

Under this condition, the trailer would have to contend with two loads, first, the tractor weight; two, its own weight. For the trailer to be able to operate such that it would have to stop the tractor and itself with the additional load on it, the dynamic supporting force at the drawbar would be so high such that it would be very unsafe for operator to drive a tractor without a functional brake. In fact, in addition to the static weight of the trailer, the force required to brake the trailer and the tractor would be inappropriate to be supported by the braking facility on the trailer alone.

**iii. When the tractor and trailer are equipped with braking facility**

This condition provides the most suitable braking control system for tractor-trailer system. From equations (3) and (6), the force required to stop the tractor-trailer system when tractor alone and trailer alone are equipped with braking facilities are high compared to the force required to stop the tractor-trailer system when the tractor and trailer are equipped with braking system. From the study, the analogy revealed that the force requirement by the tractor-trailer combination is the smallest. Definitely there will be minimal load transfer from the trailer onto the tractor. This will not only reduce risk of overturning downhill, it will also reduce slippage downhill since the braking system on the trailer would have reduced to the barest minimum the weight transfer.

This will not only improve the operation of the tractor-trailer system on the farm road and highway but will also ensure the safety of the operator and the produce being conveyed.

#### **4.0 CONCLUSIONS**

An appraisal of safety of tractor-trailer braking system was studied by developing simplified equations for the simulation of tractor responses to dynamic trailing loads with a view to coming up with the best braking option of operating tractor-trailer combination. Results from the study showed that it would be in the best interest of the country if effort is geared towards importing agricultural trailer wagons designed with separate braking systems connected to the tractor through the hydraulic system. This would reduce to the barest minimum dangers associated with tractor-trailer operation.

#### **5.0 RECOMMENDATION**

With this concept analysis, the Federal government should come out with a policy statement that importers of agricultural equipment and tractors (especially trailer wagon for farm transportation) should ensure that trailer wagons are equipped with a separate braking facility connected hydraulically to the tractors. This will reduce risks in driving tractor-trailer combination on the highway as well as on the farm road. This will also reduce the propensity of tractor operator susceptibility to accident and also reduce to the barest minimum the damage to the farm produce being conveyed.

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## **NOTATIONS**

$R_1$  - front wheel supporting force

$R_2$  - rear wheel supporting force

$R_3$  - trailer wagon supporting force

$W_1$  - weight of the tractor

$W_2$  - weight of the tractor

$a_1$  - acceleration of the tractor

$a_2$  - acceleration of the trailer wagon

$a_3$  - acceleration of tractor and trailer

$b$  - centre of gravity of trailer from ground surface

$h_1$  - height of C.G. of tractor from ground surface

$Pd_1$  - dynamic supporting force at drawbar when tractor is braked.

$Pd_2$  - dynamic supporting force at drawbar when trailer alone is braked

$Pd_3$  - dynamic supporting force at drawbar when tractor & trailer are braked.

$L$  - wheel base of tractor

$L_1$  - wheel base of trailer

$L_2$  - distance from C. G. of trailer to drawbar joint.

$L_o$  - distance from C. G. to front wheel

$G$  - acceleration due to gravity

$C$  - coefficient of friction.

$D$  - drawbar load reacting vertically at the trailer hitch point

$P$  - drawbar load reacting horizontally at the trailer hitch point.