A study on cause of rollover of sugar cane haulage semitrailer truck in Ethiopia sugar estate: case of Wonji sugar factory

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Abstract — *The Ethiopian sugar industry is one of the highly mechanized sectors of the economy in the country. Unfortunately, due to the extensive expansion projects in the Ethiopian sugar industry and due to the establishment of huge cane farms, the distance between cane farms and the cane mill has increased drastically. During transporting of sugarcane the extent of rollover accidents of the truck tractors has reached an alarming rate and it is incurring huge material and financial losses on the corporation. In this work the possible factors for rollover are studied from technical and non-technical point of view. The conclusion drawn from this study is that the rollover threshold is found 0.29g of lateral acceleration, this shows there is high center of gravity and leads the vehicle to rollover on curve easily. The drivers' action and the road condition has contribution for the accident to occurred.*

Keywords— *Roll over, Sugar cane, Semi-trailer truck, balancing.*

I. Introduction

Sugarcane transport system in Ethiopia has undergone many changes and has been streamlined to reduce costs as well as to accommodate the wide range of topographical under which sugarcane is grown in Ethiopia. Now a days the Ethiopia sugar estate exercise to use some high bed semitrailer truck with higher carrying capacity up to 40 tons in considering to the factory crushing capacity per day and to provide reliable supply of sugarcane to factory without delay , because the tractors are less in speed and pay load capacity, while in operation but these semitrailer trucks is preferred by decreasing the trips ,fast transporting and provides a huge ton of cane as compared with the carrying capacity of tractors .But in contrary to these advantages these high bed semitrailer truck has a frequent problem of loosing stability and rollover on cornering The prime objective of cane transport systems is to convey cane from the field to the mill within a minimum time-frame and at a minimal cost [2]The roll stability of vehicles is one of the most important measures of vehicle safety. When The vehicles which are used for transportation of freights via roads across the world are called as commercial vehicles. According to the information by US National Highway Traffic Safety administration [3] there are so many accidents caused due to the inferior roll stability of heavy vehicles compared with light vehicles made them more likely to roll over[1]. In many cases, truck rollovers are caused by excessive speed as trucks negotiate short radius curves . The use of long articulated vehicles is economically attractive due to lower fuel and higher tone of cargo per single trip. However it has been shown that poorly designed multiple unit vehicles can suffer from dangerous roll and handling instabilities. The semitrailer which is fabricated locally in Ethiopia under Alami Industrial Engineering company in Addis Ababa and delivered to the sugar estate, has a problem of rollover. In this work an attempt is made to study the influence of vehicle condition (static rollover threshold), conditions of the road with speed limits on curve, and the driver action on the cause of rollover accident.

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II. MATERIALS AND METHODS

To come up with suitable and appropriate solution for prevention rollover of sugar cane haulage the following materials and procedure were used from the technical and non-technical point of view of the accident. The methodology used to assess the cause of rollover were the statistical data analysis technique (primary and secondary data) collection methods for non-technical points and using equations to analyzes analytically the effect of height of center of gravity for static rollover threshold (lateral acceleration) and the effect of road geometry. Preliminary survey of the possible cause and additional expenditure incurring for the rollover were compiled using primary data collection methods; that is questionnaires were prepared and randomly distributed for twenty high bed semitrailer haulage drivers and ten management bodies in the sugar estate and also informal interview and discussion were conducted with some concerned bodies and mechanics from manufacturer of the semitrailer.

A. Determine the rollover threshold

Rollover crashes are complex events that reflect the interaction of driver, road vehicle, and environmental factors. A vehicle's resistance to rollover is measured by the maximum lateral acceleration that can be achieved without causing rollover. This maximum acceleration, measured in units of the acceleration of gravity (g), is known as the rollover threshold. The rollover threshold of a truck is largely a function of its loading configuration. In this research the effect of following parameters of a truck's loading configuration on its rollover threshold was studied.

- center of gravity (CG) height
- overall weight

Determining the value of the rollover threshold which is expressed as lateral acceleration of the centrifugal force by considering the suspension and tire compliances of the vehicle The following basic formula is used to calculated analytically and identify the propensity of rollover based on the measured vehicle parameters.[5].

$$\frac{a_{yT}}{g} = \frac{t/2}{(h_1+h_2)+\frac{h_2}{(K_{\emptyset}-1)}} - \frac{1}{C_R} \quad (1)$$

Where :

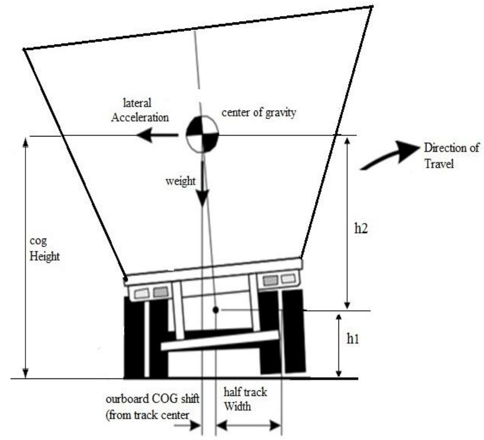
a_{yT} =lateral threshold acceleration

T = track width

h_1 =height of roll center and h_2 = payload height of c,g

$K^{\emptyset}$ = suspension roll stiffness

C_R = stiffness of tire



Vehicle Parameters that influence vehicle roll stability

Fig .2.6 commercial vehicle in a turn

B. Determine (t/h)

The T/2H is the most fundamental vehicle property relating to roll stability. Further, in practice, T/2H varies considerably, largely due to the variations in H.Thus, it is both necessary and, at the screening level, sufficient to regulate T/2H in order to regulate roll stability, However, T is so very easy to measure compared to H that excluding it provides very little benefit in reduced burden The more difficult portion of calculating T/2H is determining H, while keeping the Methodology simple. Indeed, a workable scheme to calculate a representative value of H for payload units is the key to establishing a workable and worthwhile system,

. The basic equation for determining H is:[4]

$$H = \frac{H_E W_E + H_P W_P}{W_E + W_P} \quad (2)$$

where:

WE= is the certified weight of the empty unit.

Wp= is the maximum weight of the payload specified by the applicant.

HE= is the cg height of the empty vehicle, determined by approved calculation or test, or assumed to be 1905 mm (75 inches).

Hp =is the cg height of the payload estimated with the prescribed procedure.

The key parameter in this calculation is, of course, the height of the payload cg. The procedures for determining this value depend on the type of vehicle and/or the type of freight.

For LTL packaged freight: Hp = the 40% point between the load floor and the top of theload space. That is:

$$H_P = H_F + 0.4(H_T - H_F) \quad (3)$$

where:

H_F= is the height of the floor of the load space (weighted average by area if the floor is not level).

H_T = is the top of the load space, (ceiling height if applicable, or legal limit).

C. Suspension Roll stiffness

Roll stiffness is a measure of a suspension system's resistance to rolling. As a truck body rolls, the vertical springs deform to cause a resisting moment. This moment is dependent on the vertical spring constants and lateral spacing of the springs. The height of the roll center plays an important part in the rolling tendency of a vehicle. there are two options for determine the roll stiffness of leaf springs ,using analytical formula shown in equation 3.2,[7] or a software package called spring stiffness calculator used to calculate the roll stiffness of the leaf spring [6].

Leaf Spring rate stiffness (Ks)

$$= \frac{8 \times n \times b \times E \times t^3}{3L^3} \quad (4)$$

Where:

b is the width of the leaf spring (m),

L is the distance between the eyes of the spring when laden (m),

t is the thickness of the leaf blade (m),

n is the number of leaf blades, and

E is the modulus of elasticity, which (modified to allow for internal friction) is 210 x 10^6 kN/m^2 or 210KN/mm^2

Their for ,total suspension stiffness is expressed as an effect on the lateral separation distance between the left and right leaf spring assembly is given by ,

$$K\emptyset = \frac{1}{2} Ks\, S^2 \quad (5)$$

But, roll stiffness is expressed in terms of degree or radians because whenever the rollover had happened there is a tendency of shifting center line of an axle as well as c.g of the payload due to the lifting of the inner wheel for this effect equation (5) becomes

Roll stiffness ($k^{\emptyset}$) = Ks x s^2 x 0.008729 N m/deg (6)

Where :

Ks = vertical rate of each left and right springs

S = lateral separation between springs

C. Tire vertical stiffness

The vertical deflection of a tyre is closely proportional to the applied vertical force. It is convenient to refer to this as vertical stiffness or tyre spring rates. The actual vertical stiffness of the tyre depends upon size, construction and inflation pressure. However 90% of the tire stiffness comes from inflation pressure, the tire is effectively a gas spring.[11] and the equation below is used to find the stiffness of a given tire [8]

$$C_R = 2.6P\sqrt{(sw)(D)} + 40Sw \quad (7)$$

Where : D= tire diameter (in)

Sw= tire section width (in)

P= inflation pressure (psi)

CR= tire stiffness (lb/in) , convert final result into N/m

The following necessary input data for determine the value of lateral threshold acceleration were collected from direct measurement and calculated using the above equations.

Table 3.1 Important variables in determine rollover threshold

s/no	Parameters		Values	Remarks
1	Track width	T	1.85	
2	Height of c .g of payload	H1	1.72*	Using equ.(2) and(3)
3	Height of suspension roll center	H2	0.9	Direct measure
4	Tire section width (in)	Sw	11	
5	Tire inflation pressure (psi)	P	110	
6	Lateral separation b/n suspension (m)	S	0.9	
7	Number of leaf spring	N	14	
8	Length of leaf spring	L	-	Different in length
9	Thickness of leaf spring(cm)	T	1	
10	Width of leaf spring(cm)	B	10	
11	Total Suspension roll stiffness (kN.m/deg)	$K_{\emptyset}$	2433*	Using software
12	Tire vertical stiffness (KN/M)	C_R	1275 *	Using equ. (7)
13	Diameter of tire(in)	D	44	

D. Weighing the truck combination to deciding max. Payload

Among different reasons for the cause of rollover of commercial vehicle overloading on the payload is the one creating stress on tire and suspension that affect handling and stability performance as well as damages different parts of the vehicle like accelerating tire wear and frequent bearing damage. To determine suitable load conditions ,The selected truck were taken to the weighbridge which is found at the sugar estate for determine optimum payload based on the axle load carrying capacity and the tare weight of the trailer. To determine the over all weight distribution of the trailer it is important to fined the load of the trailer on the fifth wheel king pin using the equation shown below.

Payload at kingpin [truck buyer guide published in Australia, sep.2011]

$$PL_{kp} = \frac{W \ X \ D}{WB} \qquad (8)$$

Where : w= gross trailer tare weight

WB= wheel base of trailer

D = the distance b/n payload c.g and kingpin

After weighing The truck and semitrailer combination the following parameters were collected .

Table 3.2 weight of vehicle and axle load carrying capacity

no	Parameter	Values
1	Tractor weight alone	9200kg
2	Trailer weight alone	12300 kg
3	Steering axle load range	7000kg
4	Tandem axle load range	18000kg
5	Fifth wheel vertical load	15670kg
6	Tractor load distribution (F/R) %	74/26
7	King pin set back (m)	1.57
8	Total GCVWR	40000 kg

Source: taken from manual and weighing the truck

E. Determine of minimum speed of the vehicle on curve

Super elevation may be defined as the raising of the outer edge of the road along a curve in order to counteract the effect, of centrifugal force acts on the vehicle and the stability of the vehicle is disturbed. The speed of the vehicle on cornering is the one which is creating centrifugal force that leads the vehicle in to rollover conditions The equation below is used to determine the minimum radius of curvature that can be traversed at any given speed [9 &10]. In practice, four values of e_{max} are used, being 4, 6, 8, and 10 percent. The selection of the appropriate value of e_{max} is at the discretion of the designer in terms of the design domain concept. The higher values of $_{emax}$ are typically applied to rural areas and the lower values to the urban environment. A super elevation rate of 10% implies that the roadway surface elevation increases by 1 ft for every 10 ft of roadway width. The side-friction factor is simply the coefficient of friction between the design vehicle's tires and the roadway. For any given speed, it is thus only necessary to select the maximum rate of super elevation, e_{max}, in order to determine the minimum allowable radius of horizontal curvature for that speed. [10]

$$R_{min} = \frac{V^2}{127(e_{max} + f)} \qquad (9)$$

but side friction factor can be taken as

f = 0.21 – 0.001xV (9a)

where:

V= vehicle design speed (km/h)

e = super elevation(taken as positive when the slope is downward towards the centre of the curve)

R= radius of curvature of a road section (m)

f= side friction factor

The following table shows the existing road parameters at different places were Under Wonji sugar estate harvesting road.

Table 3.3 road geometry for selected area in wonji sugar estate

Road parameters	field number with frequent Rollover incident				
	48	wolenchity	171	172	69
Radius of curve	25	28	25	21	23
Friction factor *	0.183	0.183	0.183	0.183	0.183
Supper elevation	0.08	0.059	0.04	0.061	0.068
Length of curve l1	39	28	30	24	26
Length of curve l2	34	28	35	30	24

*calculated value using eqn. (9.a) and 25km/h design speed of the road

III.RESULTS AND DISCUSSIONS

For the success of the study data's which were collected from questionnaires and interview are summarized and tabulated for discussion as shown below.

Table 4.1 Summary of results from questionnaire

No	Item	Selection	Frequency	Percentage
1	Selection criteria of drivers in sugar estate	Promotional Up grading *	16	80%
		Hire from out side	4	20%
		Both	10	
2	Types of vehicle the driver mostly drives	Automobile	7	35%
		Light vehicle	3	15%
		Medium/tractor	5	25%
		Heavy duty	5	25%
3	Operators driving experience on HBT of sugarcane haulage	Below 1 year	13	65%
		1- 5 year	7	35%
		5- 10 year	-	
4	Training given to drivers about HBT	Yes	16	80%
		No	4	20%
5	Duration of training	Less than 2 week	16	100%
		1- 2 month	-	
		Above 2 month	-	
6	Drivers who met Rollover accident During operation	Yes	12	60%
		No	8	40%
7	Number of HBT in wonji sugar estate	15	8 rolloverd	53.3%
8	Cause of the rollover of HBT	Drivers	11	27.5%
		Road factor	9	22.5%
		Vehicle condition	18	45%
9	The Place where the rollover Accident mostly occurred	Curve	13	65%
		Sloppy land	4	20%
		Up and down hill	2	10%
		Straight road	1	5%

Secondary data collected from for analysis of the additional expenditure incurring due to the rollover of HBT in sugar estate for one year presented in table 4.2

Table 4.2 Maintenance and insurance expenses' made for rollover accident

No	Description	Amount (EBR)	Semitrailer	Total (EBR)
1	Maintenance work for 15 semitrailer *	60,000	15	900,000
2	Insurance payment for rollover accident **	235,000	6	1,410,000
3	Insurance payment for total loss due to rollover **	750,315.69	1	750,315.69
	Total			3,060,315.69

Source :- **wonji sugar factory insurance dep. and *workshop/ garage report

A. **Analysis's on the value of lateral acceleration and static rollover threshold**

The value of height of c.g of the payload was found 2.25m and the roll center height was around 0.9 m from the ground, using the equation the lateral acceleration was found 2.9m/s^2 and the rollover threshold was 0.29 at this height of c.g of the payload .But this result shows the propensity of rollover is much higher. By fixing other parameters constant in the equation and by varying only the height of c.g of the payload it is possible to achieve the required value of rollover threshold for commercial vehicle which is stated on literature review range between 0.3 -0.35.

Table 4.3 result of static rollover threshold

track(m)	h1(m)	h2(m)	K_φ(N/m)	CR	$(ay)^T/g$	$(ay)^T$(m/s^2)	tan($(ay)^T/g$	v2(m/s)
1.85	1.35	0.9	40.36	6.7	0.296156	2.90529193	16.968498	7.994775
1.85	1.25	0.9	40.36	6.7	0.312737	3.06794955	17.918508	8.757782
1.85	1.1	0.9	40.36	6.7	0.341193	3.34710748	19.548943	9.680858
1.85	1	0.9	40.36	6.7	0.362995	3.56097975	20.798074	9.050002
1.85	0.9	0.9	40.36	6.7	0.387501	3.80138492	22.202172	8.719386

B. **The Surveyed road parameters result**

The road parameters collected from selected curve were analyzed using the equ. (9) and the following result found using excel.

Table 4.4 design speed range super elevation for given road curvature

Feld no	radius of curve (m)	v^2(km/h)	F	e max
Adulaa	22	28	0.182	0.098601
5	56	43	0.167	0.092983
92	52	31	0.179	0.091247
171	25	29	0.181	0.083882
84	20	26	0.184	0.082142
172	21	27	0.183	0.090341
50	23	28	0.182	0.086401
Dodota	70	48	0.162	0.097168

IV. CONCLUSIONS

Based on the results obtained from the study the following conclusion is drawn.

Among different factors for rollover accident the driver input into the system plays a great roll next to the vehicle conditions .The driver selection criteria in wonji sugar estate has an impact because most drivers of automobile and light vehicles were promoted to those haulage trucks as long as they held the driving license but the skill ,safety and experience of driving is vary for different vehicles category. Regarding the training most driver attend it, but the subject matter were not provided them the required knowledge about types of accident and its prevention specially for commercial vehicle ,enough practical driving session in different load condition. Therefore as the result of this investigation the contribution of the drivers for rollover accident of those HBT in Wonji is high.

In analyzing of the vehicles axle load carrying capacity with the tare weight of the trailer excess weight on GVWR and due to high payload c.g 0.29 rollover threshold value was attained due to this those truck tends to rollover easily especially on cornering and also component wear and damage . Regarding The road condition of Wonji sugar estate it has an input to rollover accident due to the presence of low super elevation and low radius of curvature .The absence of driving speed range particularly for the harvesting road, the drivers do not know what should be the speed of the tuck at the time of negotiating into the curve. As the curvature of the roads are varied it is requires to set average design speed limit for harvesting road.

Generally, For the cause of rollover of those sugar cane haulage the effect of the vehicle condition for its higher c.g due to the bin is built over high bed chassis, and the shape of the steel frame structure which is protruded to both side of the truck that leads to lose in stability of driving especially on curve. And also the geometry of the road condition for its less in radius of curvature and the minimum speed of the truck while on curve road is not specified. Lastly the driver selection criteria in sugar estate is not considered the skill and the training given to the drivers is not include the dynamics of heavy commercial vehicle and is not supported with practical lessen.

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