Intelligent Route Guidance for Heavy Vehicles

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Table of contents

List of Abbreviations

Abbreviation	*Meaning*
LCPC	*Laboratoire Central des Ponts et Chaussées* *(Central Laboratory of Bridges and Roads)*
LRPC	*Laboratoire Régional des Ponts et Chaussées*
BAAC	*Bulletin d'Analyse d'Accident Corporel de la Circulation* *(Sheet analysing the traffic accident causing death or injury)*
HV	*Heavy Vehicle*
RO	*Rollover*
DOF	*Degrees Of Freedom*
LTR	*Load Transfer Ratio*
COG	*Centre of gravity*
CO Roll	*Centre Of Roll*
PROSPER	*PROgramme of SPEcification and Research components (Professional vehicle dynamics simulation)*

List of Figures

List of Tables

Executive Summary

The parameters variations of the heavy vehicle can influence its safety. A small or a big variation of each parameter can cause critical situation like rollover or jackknifing, since it can change significantly the vehicle state. Different variables are tested in this report to show their influence on the heavy vehicle dynamics and on the risk.

This study is very important to know the most influential parameters on the rollover risk of the heavy vehicle. It permits us to focus our study on these critical parameters variations and to neglect the others.

For example, when the vehicle is empty (Total mass variation), it becomes much more instable. The vehicle is then more sensible to rollover.

The centre height of gravity is the other important parameter: when the vehicle is higher it becomes more instable and can cause rollover especially in the curvature with a high speed.

The influence of the speed is also shown in this study. The tests used are those which correspond to the cases where there is no speed variation.

A maximum speed from which rollover risk occurs is then calculated.

The road characteristics can also influence the dynamics of the heavy vehicle: the significant variations of road profile, skid resistance, radius of curvature, longitudinal and lateral slop can destabilise the vehicle and cause the rollover. Taking into account these road parameters in the heavy vehicle model and in the sensibility study is then very important to know how their variations can influence the dynamics of the vehicle.

The sensitivity study depends then on the heavy vehicle model characteristics. The model chosen is the simplified Ackermann model with three degrees of freedom developed in this report and validated using PROSPER's software simulator. Many others tests which are not mentioned here, are done using this simulator to show the robustness of the method. The aim is to work with a lot of kind of heavy vehicle models (tractor single unit, tractor-semi trailer…) with many different inputs and scenarios.

The only difficulty of this study is to know exactly the heavy vehicle parameters. It's very difficult to have them from constructor. The solution is then to work with the parameters given by PROSPER. It will be necessary to confirm their values.

1 Introduction

The aim of this report is to study the effect of the trucks parameters on the vehicle dynamics which governs it safety. This study will be realised using the vehicle/infrastructure models which are designed in task 2.4. We choose to work with a developed simplified model of Ackermann and with PROSPER's simulator.

The research is based on a parameters sensibility analysis in order to determine the most influent parameters on vehicle dynamics and its safety (Centre height of gravity, Mass, road characteristics, speeds…). A large number of simulations will be produced with different values of vehicle parameters. First, simulations are done on developed heavy vehicle model (Ackermann model) then in the second part, other tests are done using software simulator PROSPER.

In the report, we simplify the study since we work with linear model of heavy vehicle with three degrees of freedom and which takes into account only the skid resistance. Other road characteristics like road profile, longitudinal and lateral slop and radius of curvature, are neglected.

2 Influence of the vehicle characteristics on vehicle/road interactions

2.1 Description of the trucks accident due to vehicle/road interactions problems (adding some statistics):

2.1.1 Statistics

The aim of this part is to provide the most relevant and most permanent data on accidentology.
Our general knowledge of accidents and their causes basically come from BAAC (Sheet analysing the traffic accident causing death or injury) records which are filled in by the police after each accident causing death or injury. For this aspect, reference will be made to the chapter on the file of accidents causing death or injury [1].
A necessary requirement: evaluating the risk. The great methodological difficulty, in the field of accidentology, lies in not being content to appraise the frequency of accidents but to evaluate the danger, in other words, the frequency of accidents in relation to exposure to the danger which is often the number of kilometres covered, but which can be another variable. It is not enough to note a greater frequency of a particular factor in accidents, it must be checked that there is a greater frequency in the traffic. It is often here that data are lacking or are inaccurate and this is the reason why a certain amount of additional enquiries must be carried out to obtain information on the journeys made.

The heavy vehicles constitute the population of vehicles for which the rate of serious accidents is highest. In more of serious consequences in human terms for the road users, these accidents generally induce major congestions, attacks with the environment or the infrastructure at the important economic costs. It appears urgent to act, more especially as it is estimated that the road transport of goods should grow approximately 40% within ten years [2].

The accidentology study, carried out by Renault Trucks, made it possible to identify the most frequent typology of accident among those implying an insulated heavy vehicle. It acts of rollover in 60% of the cases. The most represented silhouette is the tractor unit and semi trailer, which corresponds to 80% of the heavy vehicles implied in the rollover.

The Lyon's Register data base shows the extent of the motorway traffic and the relatively low portion occurring on them; the substantial portion of the main roads and secondary roads from the standpoint of accidents and deaths with a considerable linear element, which makes both surveillance of this network and its safety more difficult. It enables an understanding of the extent of the density in all space comparisons (between departments or countries5). The motorways are 4 times less dangerous than the main roads (0.25 death rate per 100 million km covered while the main roads have a rate of 1.08). In 10 years, the two networks have seen this rate decline considerably6. According to the studies carried out by the motorway companies, 31% of people killed on motorways were not wearing a seat-belt7, 32% of accidents causing death or injury are rear collisions or pile-ups. Head-on collisions are very rare (0.6% of accidents) but very serious (11 deaths in 2004).

2.1.2 Infrastructure characteristics

From statistical data (BAAC), we know that 73% of accidents occur in straight line. From BAAC, we know also that 77% of accidents occur on the plane road and 19% on longitudinal slop [3]. 76% occur on the normal road and 20% occur on wet road. These results are not the same like those given by the north countries where they show that there is no influence of the skid resistance on heavy vehicle.

These data show, that the road geometry influences on the number of accidents as follows:

- There is almost the same number of accidents on curvature than straight line (respectively 42% and 57%),
- There are two times more accidents in the right curvature than the left one (respectively 25% and 13%),
- The longitudinal slope has the same influence on the accidents whatever the number of implied vehicles.

These results are summarized in the next Table:

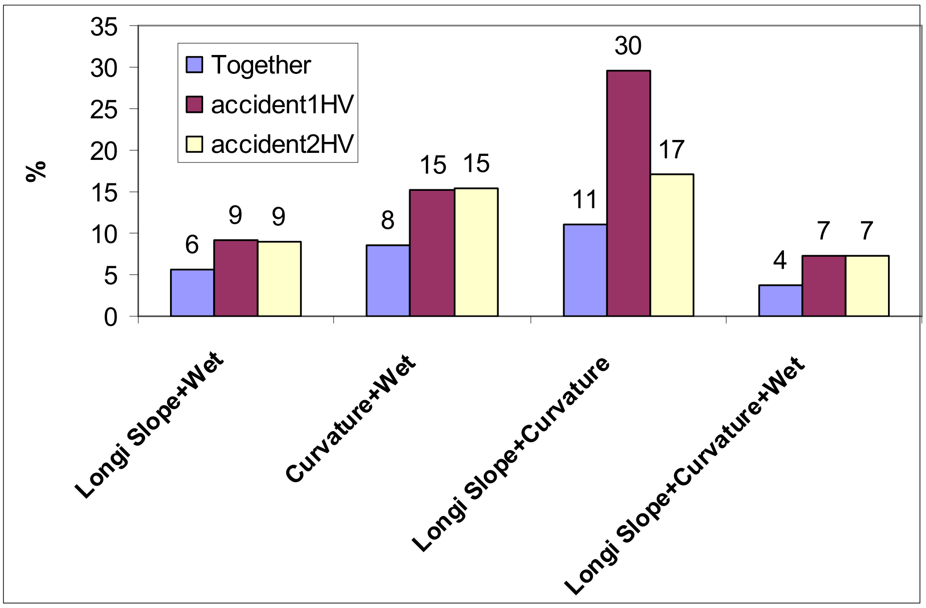


Figure 1: Accident repartition in Rhône-Alpes region (France)

2.2 Heavy vehicle model

2.2.1 Model description

The sensitive study is done on the heavy vehicle model described in the figure 2. The model was developed by J. Ackerman and D. Odenthal ([4], [5], [6]). Therefore, some hypotheses were considered: the vehicle is moving on a flat and level road with a constant longitudinal speed, the roll angle is assumed to be small, suspension and tire dynamics are assumed to be linear.

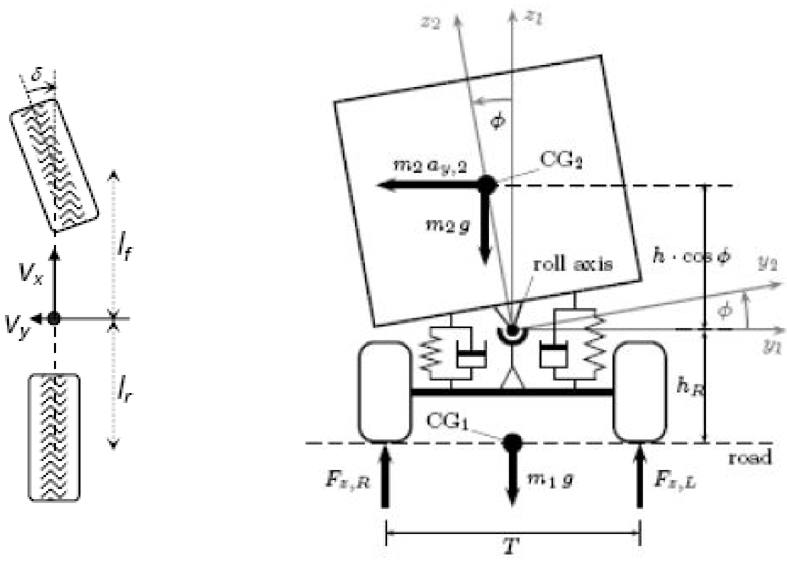


Figure 2: Heavy vehicle model with 3 dof

This model is used to rollover risk study of non articulated vehicles with two axles.
It is a simplified model of a heavy vehicle, composed of two principal bodies: the body C_1 which is the unsprung part of the vehicle (unsprung mass, four wheels and front axles), and the body C_2 which represents the sprung mass.

The equations of the model are:

$$\begin{cases} mv\dot{\beta} - m_2 h\ddot{\phi} = F_f + F_r - mvr \\ J_z \dot{r} = l_f F_f - l_r F_r \\ (J_{2,x} + m_2 h^2)\ddot{\phi} + c\dot{\phi} + (k - m_2 gh)\phi = m_2 h a_{y,1} \\ a_{y,1} = v(\dot{\beta} + r) \end{cases}$$

Where: F_F and F_r are respectively the front and rear of pneumatic lateral forces. For our application, these forces present a linear domain near from the origin. According to the side angle $\alpha = \delta - (\beta + l_f\, r/v)$, these forces are calculated as:

$$F_f = \mu\, c_f\, \alpha \quad \text{and} \quad F_r = \mu\, c_r \alpha$$

where:

μ represents the skid resistance, β is the steering angle and v is the vehicle speed.

The movement equation of the model can be rewritten as:

$$M\ddot{q} + D\dot{q} + Kq = Su \tag{1}$$

where:

$$M = \begin{bmatrix} m & 0 & -h\, m_2 \\ 0 & J_z & 0 \\ -h\, m_2 & 0 & J_x + h^2 m_2 \end{bmatrix} \qquad Kq = \begin{bmatrix} 0 \\ 0 \\ \phi\,(c - m_2\, g\, h) \end{bmatrix} \qquad S = \begin{bmatrix} c_f\, \mu \\ c_f\, l_f\, \mu \\ 0 \end{bmatrix}$$

$$D = \begin{bmatrix} \dfrac{c_f\, \mu + \mu\, c_r}{v} & \dfrac{c_f\, l_f\, \mu - \mu\, c_r\, l_r + m\, v^2}{v} & 0 \\ \dfrac{(c_f\, l_f - c_r\, l_r)\, \mu}{v} & \dfrac{(c_f\, l_f^{\,2} + c_r\, l_r^{\,2})\, \mu}{v} & 0 \\ 0 & -h\, m_2\, v & d \end{bmatrix}$$

$q = [y, \psi, \phi]^T$ represents respectively, the transversal position, yaw angle and the roll angle and $u = \beta$.

We can rewrite the system in the state form as:

$$\dot{x} = \begin{bmatrix} 1 & 0 \\ 0 & M^{-1} \end{bmatrix} \begin{bmatrix} 0 & [0,0,1] \\ -K & -D \end{bmatrix} x + \begin{bmatrix} 1 & 0 \\ 0 & M^{-1} \end{bmatrix} \begin{bmatrix} 0 \\ S \end{bmatrix} u \tag{2}$$

where:

$$x = \left[\phi\,,\, [\dot{y}, \dot{\psi}, \dot{\phi}]\right]$$

The nominal values of the considered parameters for the model of Ackermann developed in this study are coming from [4]:

Table 1: Nominal values of parameters

c_f = 582 kN / rad	Front cornering stiffness
c_r = 783 kN / rad	Rear cornering stiffness
k = 457 kNm / rad	Roll stiffness of passive suspension
c = 100 kNm / rad	Roll damping of passive suspension
g = 9.81 m / s^2	Acceleration due to gravity
h_R = 0.68 m	Height of roll axis over ground
h = 1.15 m	Nominal height of CG2 over roll axis
$J_{2,x}$ = 24201 kg.m^2	Roll moment of inertia, sprung mass
J_z = 34917 kg.m^2	Overall yaw moment of inertia
l_f = 1.95 m	Distance front axle to CG1
l_r = 1.54 m	Distance rear axle to CG1
m = 14300 kg	Overall vehicle mass
m_2 = 12487 kg	Sprung mass
μ = 1	Road adhesion coefficient
T = 1.86 m	Track width

The model is written as follows:

$$\left[\frac{dx_1}{dt}\right] = x_4$$

$$\begin{bmatrix} \dfrac{dx_2}{dt} \\ \dfrac{dx_3}{dt} \\ \dfrac{dx_4}{dt} \end{bmatrix} = \begin{bmatrix} \dfrac{(-c + m_2\ g\ h)\ h\ m_2}{det} \\ 0 \\ \dfrac{(-c + m_2\ g\ h)\ m}{det} \end{bmatrix} x_1$$

$$+ \begin{bmatrix} \dfrac{J_x + h^2\ m_2}{det} & 0 & \dfrac{h\ m_2}{det} \\ 0 & \dfrac{1}{J_z} & 0 \\ \dfrac{h\ m_2}{det} & 0 & \dfrac{m}{det} \end{bmatrix} \begin{bmatrix} \dfrac{(c_f + c_r)\ \mu}{v} & \dfrac{(c_f\ l_f - c_r\ l_r)\ \mu}{v} + m\ v & 0 \\ \dfrac{(c_f\ l_f - c_r\ l_r)\ \mu}{v} & \dfrac{(c_f\ l_f{}^2 + c_r\ l_r{}^2)\ \mu}{v} & 0 \\ 0 & -h\ m_2\ v & d \end{bmatrix} \begin{bmatrix} x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

$$+\begin{bmatrix} \frac{\mu\, c_f\, (J_x + h^2\, m_2)}{det} \\ \frac{c_f\, l_f\, \mu}{J_z} \\ \frac{\mu\, c_f\, h\, m_2}{det} \end{bmatrix} \delta$$

Where:

$$det = m\, J_x + m\, h^2\, m_2 - h^2\, m_2{}^2$$

Lateral acceleration:

The vector of lateral acceleration is expressed as follow:

$a_{y,1} = \dot{x}_2 + v x_3$

Where $x_2 = v_y$ and $x_3 = \dot{\psi} = r$

The lateral acceleration of the sprung mass is:

$$ay = \dot{x}_2 + v x_3 - h\dot{x}_4 \tag{3}$$

where $x_4 = \dot{\phi}$ is the roll speed.

Finally, we can calculate this acceleration by:

$$a_y = \left[\frac{(-c + m_2 g h)\, h\, (m_2 - m)}{det}, \frac{(c_f + c_r)\, \mu\, J_x}{det\; v}, \frac{2\, det\; v^2 + J_x\, c_f\, l_f\, \mu - J_x\, \mu\, c_r\, l_r}{det\; v}, \frac{h\, d\, (m_2 - m)}{det} \right] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \tag{4}$$

The stationary case:

In the stationary case, the state variables are constants. The lateral acceleration depends only on the longitudinal speed and the yaw rate, as follows:

$$ay = v\, x_3$$

2.2.2 Model validation

This model is validated using PROSPER's software developed by Sera-Cd [8].

PROSPER is advanced simulation software with extensive capabilities for complex heavy vehicles:

- Twin wheels,
- Up to 10 axles with complex transmissions,
- Air springs with automatic ride height correction,
- up to 4 trailers,
- Articulated vehicles,
- Mobile carriage in option.

It has the following applications:

- Vehicle conception,
- Homologation tests,
- Accident reconstruction,
- Road / vehicle compliance test,
- Advanced chassis control,
- Compare simulation measurement,
- Co-simulation,
- Real time driving simulator

Real tests validation with an instrumented heavy vehicle were performed with the PROSPER simulator and lead to validate it. The Results of these tests can be found in [9].

The figure 3 represents a comparison between yaw angle coming from prosper and that estimated by the model.

We remark that the model result converges towards Prosper one.

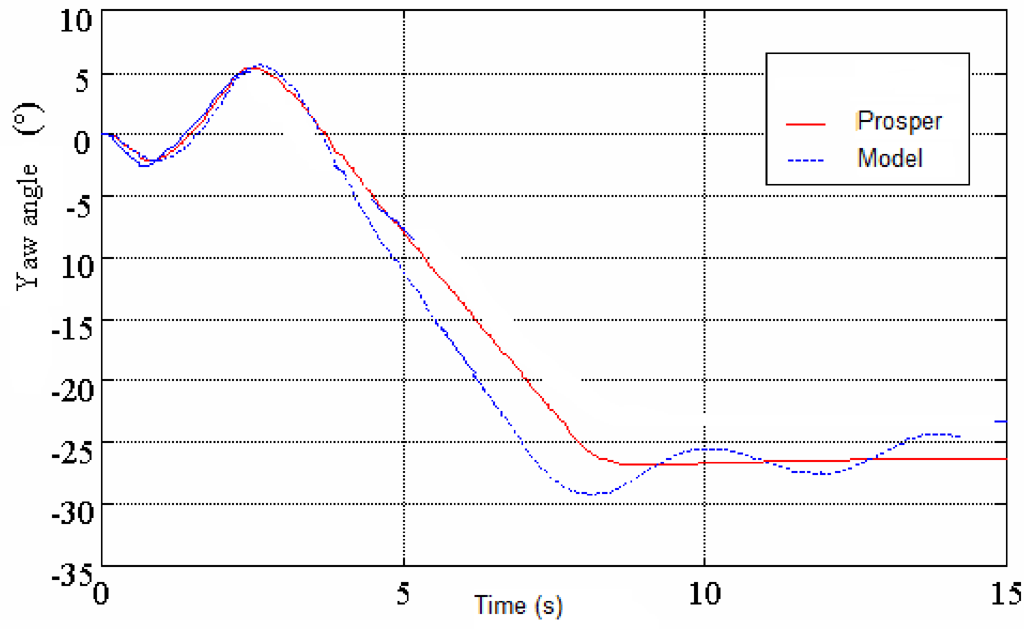


Figure 3: Validation result of the model: yaw angle

2.3 Rollover criteria

The rollover risk is obtained using the Load Transfer Ration coefficient (LTR) between the left and the right wheels of the same axle ([7], [10]).

The risk of rollover is detected when one of the wheels of the same axle leaves the ground. That is determined by the value of the reactive vertical forces coming from the ground on the wheels. A rollover coefficient is defined by establishing the balance of the vertical forces on a horizontal roadway.

We calculate it as:

$$|LTR| = \frac{|F_{z1} - F_{z2}|}{F_{z1} + F_{z2}} = \frac{2m_2}{m \cdot T}\left|(h_R + h\cos\phi)\frac{a_y}{g} + h\sin\phi\right| < R_{\lim} = 1 \qquad (6)$$

In stationary case, the LTR is described as:

$$LTR = \left[\frac{2\ m_2}{m\ T}\right]\left[\frac{(hr + h\ \cos(x_1))\ v\ x_3}{g} + h\ \sin(x_1)\right] \qquad (7)$$

When, we replace x_1 and x_3 by their values, we obtain:

$$LTR=-\frac{2m_2v^2(l_f+l_r)c_r\mu c_f u(-h_r c+h_r m_2 g h-hc)}{mT(\mu c_f c_r l_r^2+\mu c_r c_f l_f^2+2c_f l_f \mu c_r l_r-c_f l_f m v^2+c_r l_r m v^2)g(-c+m_2 g h)} \tag{8}$$

This last value is very important since it shows the dependence of LTR on each heavy vehicle parameter. The sensitivity study presented in the following part is then based on the LTR value in (8).

3 Sensibility study

In this section, we study the sensitivity of the system and the LTR related to the parameters vector p.
It was seen that the rollover coefficient LTR is a function of the dynamic state as well as parameters of the vehicle, thus it is necessary to study the influence of the variation of these parameters on the calculation of the rollover coefficient and to have an idea on the sensitivity of this coefficient towards these parameters. This study is limited for an interval of variation of the parameters between -20% and +20% which is sufficiently. In this study, we show that the LTR is strongly sensitive to the speed and the centre height of gravity of the sprung mass; it is the same case with the roll angle. It is also necessary to limit uncertainties on these parameters.

We calculate the sensitivity as:

$$S_1 = \frac{\partial LTR}{\partial p} \quad \text{and} \quad S_2 = \frac{\partial x_f}{\partial p}$$

If we have dependence of parameters, we use the following expression to calculate the sensitivity:

$$S = \frac{\partial LTR}{\partial p} + \frac{\partial LTR}{\partial p_1} \cdot \frac{\partial p_1}{\partial p}$$

It's then very important to know what the dependence of the parameters between them is.

3.1 Dependence of parameters

The aim of this part is to show the dependence between some parameters of the vehicle:

– Relation between l_r and l_f:

$$l_r + l_f = l$$

– Relation between m and m_2 (the unsprung mass m_1 is considered as constant):

$$m - m_2 = m_1$$

– Relation between c_f, c_r and μ : are considered independent

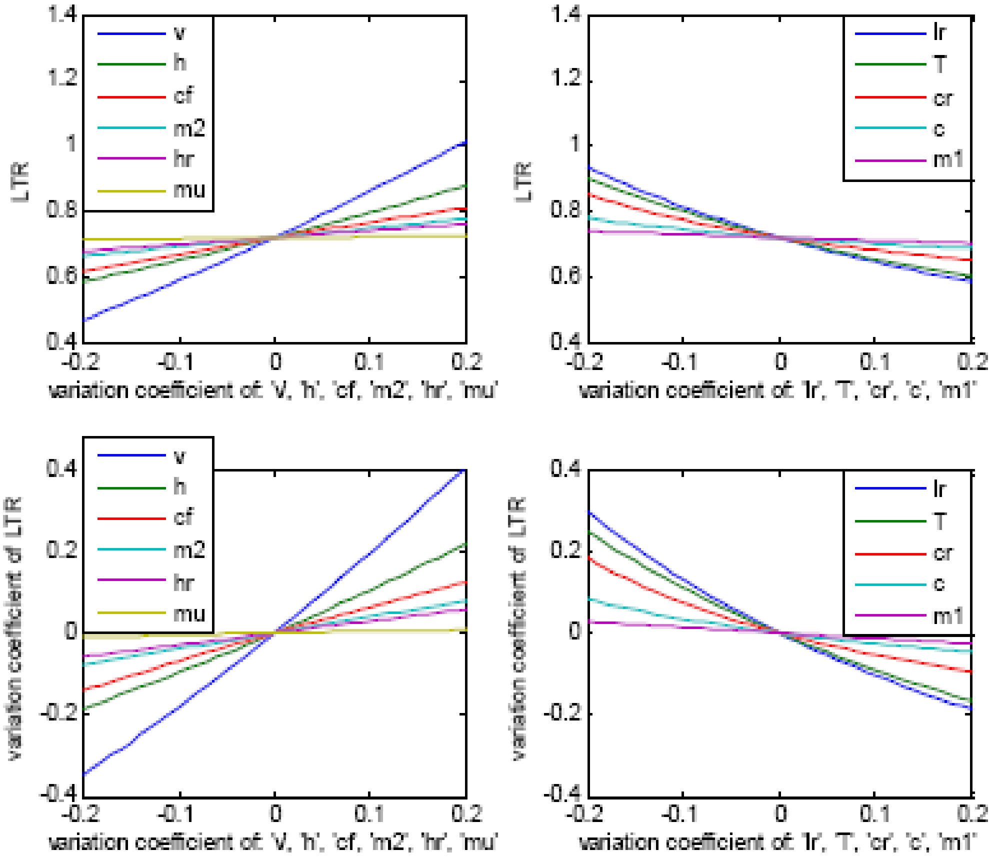
– The inertia moments J_x and J_z, h and m_2 are considered independent

3.2 Sensitivity of LTR and state vector

We give in this part, some results about the variation of LTR according to variation of the model's parameter. The influence of the parameters variation on the heavy vehicle dynamics (roll angle, yaw rate and lateral speed) is also shown [11].
The variation coefficient is defined as its variation around its nominal value.

We obtain two classes of parameters: first class implied a positive sensitivity of LTR (*Figure 4a*), and the second, implied a negative one (*Figure 4b*).

We use the nominal values given by the table 1, with a speed of 15m/s and a steering angle about 3°.



(a) *(b)*

Figure 4: LTR sensitivity with parameter variation between –20% and +20%

The classification of the parameters of the figure 4*a* is done using the influence degree around the nominal values: longitudinal speed v, centre height of gravity h, c_f, m_2 and the skid resistance μ.

This figure shows that, if the value of one of these parameters is less than the used value, the true LTR can be also less than the calculated one. An alarm can then be given without rollover risk.

Another hand, if the error in the knowledge of these parameters is negative, the calculated LTR will be lower. In this situation, we can have a risk without given an alarm.

It's then very important to work with the maximal values of these parameters and identify the most important and most influencing parameters.

The classification of the parameters of the figure 4*b* is done using the influence degree around the nominal values: l_r, T, c_r, c, and the unsprung mass m_1.

In this case, if the error in the knowledge of these parameters is positive, the calculated LTR can be also less than the true one. We can have a rollover risk without given an alarm.

It's then very important to work with the minimal values of these parameters and identify the most important and influencing parameters.

The parameters c (roll damping), J_z and J_x have no influence on LTR. They were not being considered.

The figures (5-7) show respectively the influence of parameters on heavy vehicle states (roll angle, lateral acceleration and yaw speed).

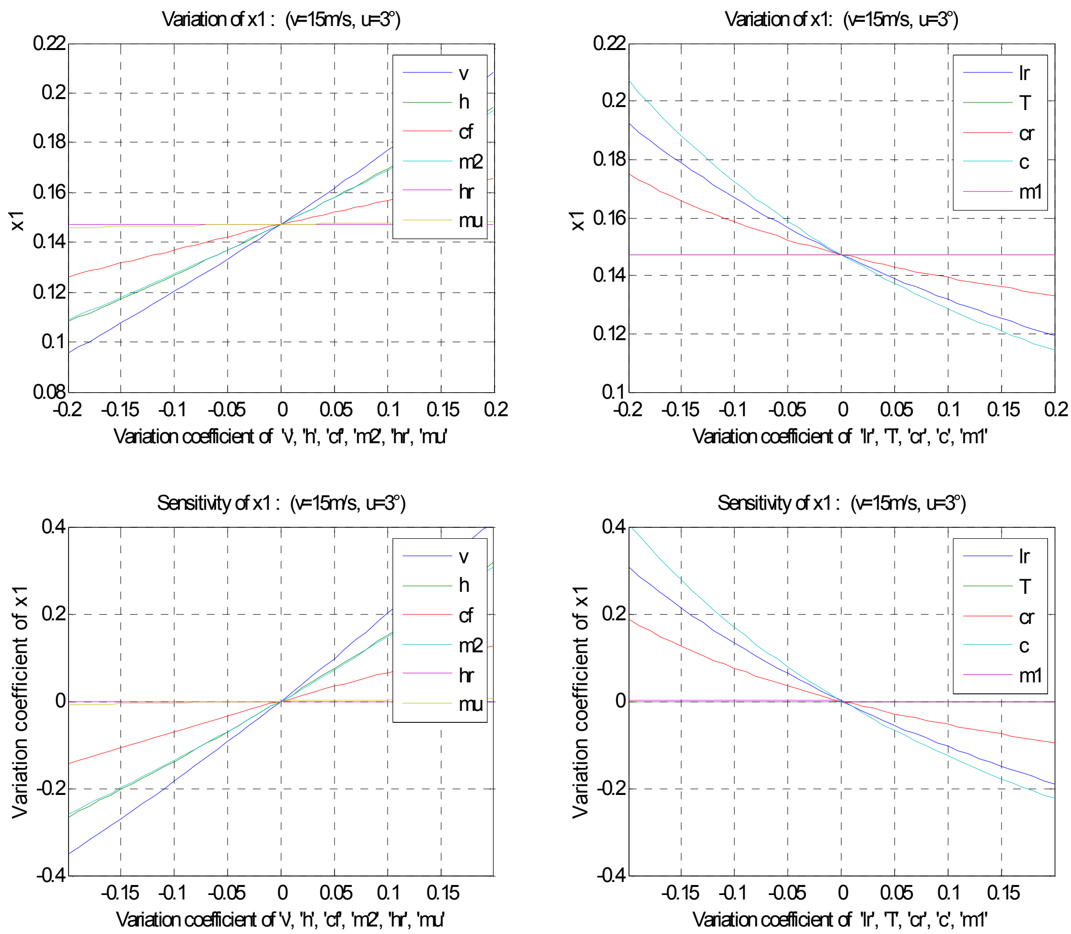


Figure 5: Influence of parameters on roll angle

The influence of the variation of the sprung mass m_2 on the roll angle is more important than in the figure 4. It has the same influence like the centre height of gravity h and the roll damping c.

Another hand, there is no sensitivity against the unsprung mass, h_2 and the skid resistance.

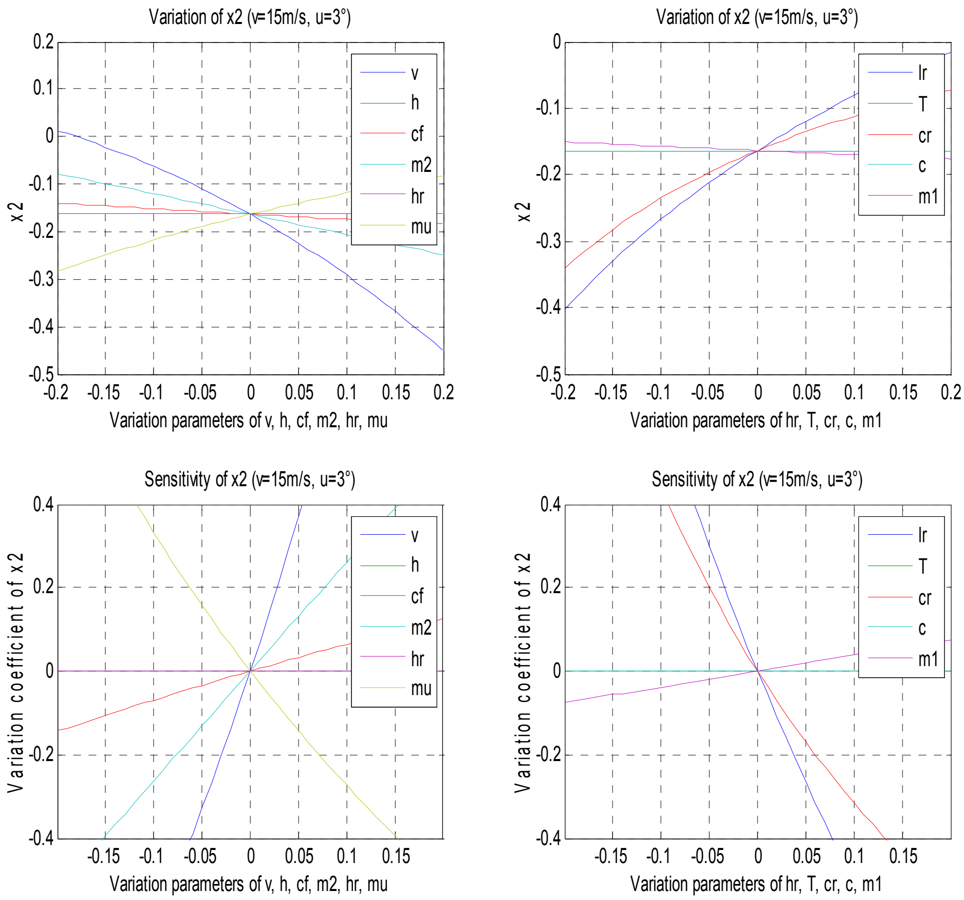


Figure 6: Influence of parameters on lateral speed

The variation of the sensitivity of lateral speed (figure 6) is not the same as LTR. The sensitivity related to the speed *v*, m_2 and c_f is negative. Related to l_r and c_r, this sensitivity becomes positive.

The skid resistance has more influence on the lateral acceleration than on the roll angle.

The centre height of gravity *h* and T are no influence.

Let see now the influence of parameters variation on the yaw rate represented in the figure 7.

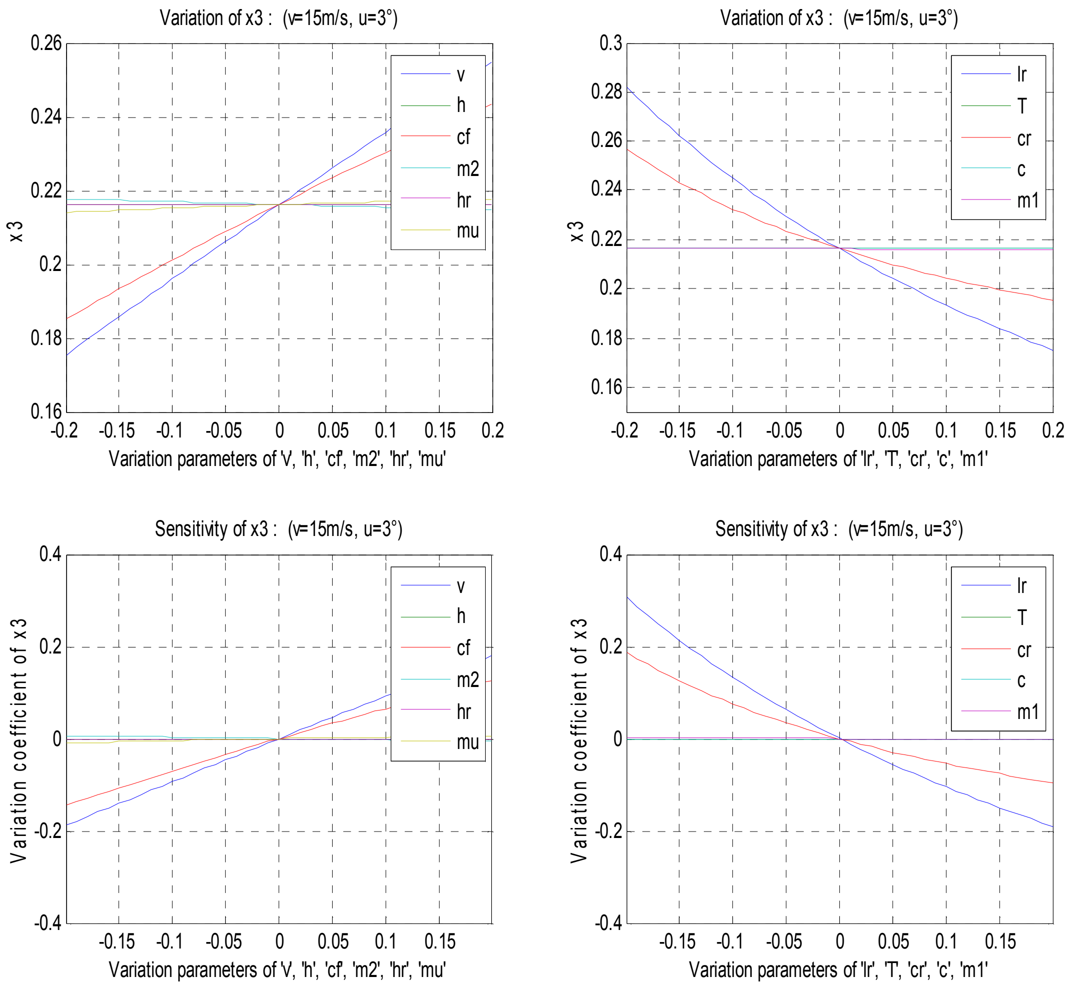


Figure 7: Influence of parameters on yaw rate

We can remark in the figure 7 that the sensitivity is important related to coefficients c_f and c_r, the position l_r and vehicle speed v. The other parameters have no influence on yaw rate.

3.3 Sensibility study using PROSPER

In this part, we use the software simulator 'PROSPER' to study the sensitivity of the parameters on the rollover. We made some simulations with PROSPER with parameters variations of the heavy vehicle.

The tests are done on curvature with constant speed.

The following figure 8 shows the profiles of the steering angles and the trajectory with a speed of 15m/s (54 km/h) in the curvature with 67 m of radius.

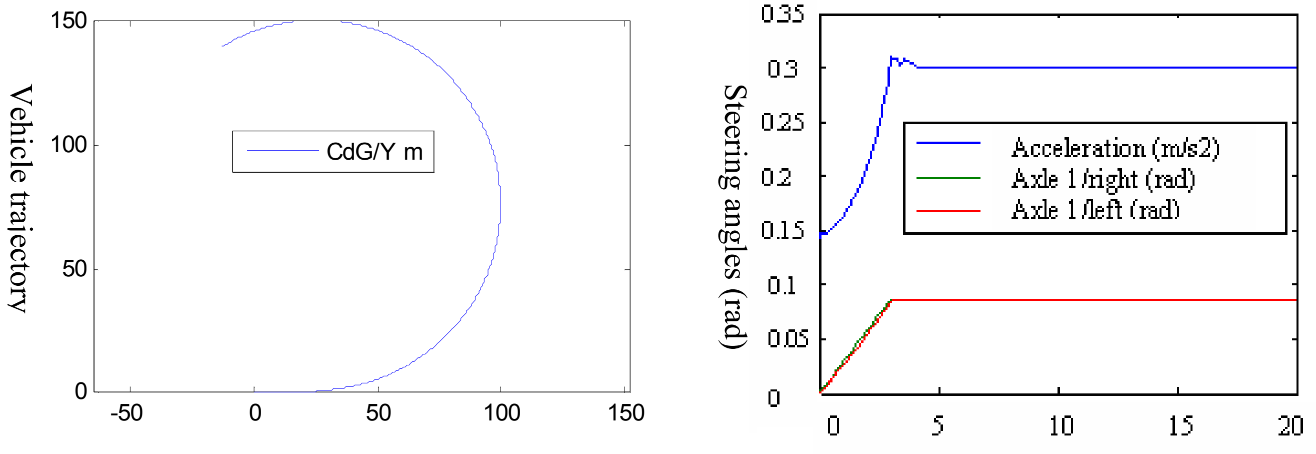


Figure 8: Trajectory and steering angles

3.3.1 Influence of Parameters variation around the rollover area

We have done several tests with different speeds. The results of these tests are given in the following table 2:

Table 2: Simulation tests

V initial (km/h)	~	**57**	**58**	~	**62**	**63**	~	**67**	**68**
V finale (km/h)		57	56.95		56.95	55.51		55.5	RO
LTR final Axle 1 Axle 2		0.736 0.841	0.753 0.879		0.736 0.841	0.731 0.827		0.731 0.827	1 1
LTR max Axle 1 Axle 2		0.736 0.841	0.736 0.841		0.793 0.981	0.927 1		1 1	1 1
Remarks	Constant speed final LTR not reached					Lower speed Wheels take off No Rollover			Rollover (RO)

Between 0 and 57 km/h, the vehicle speed is constant during all the simulation period because the cruise control of PROSPER's model could not be obtained without exceeding the maximum power of locomotion. According to the table, one notes that there is reduction speed, and that final speed is practically the same one between 57 and 62 km/h. It is 57 km/h. The reason is that the cruise control requires more power to exceed this speed.

In this table, we show that there is the rollover limit from a speed of 63 km/h. The wheels take off but not yet rollover of the heavy vehicle. This rollover is effective when the speed reaches 68km/h.

From this result, we made tests to study the parameters influence. First, we consider the case of rollover limit (67km/h). The results are shown in the following table 3:

Table 3: Parameters influence

Parameters	Nominal values	Variation sens of RO	Quantification	
			without RO	With RO
K_p		↓	–60%	–70%
K_S		↓	–35%	–40%
K_b	[6000 ; 5000] daNm/°		0	
COG height	1.552 m	↑	+1%	+2%
Roll centre height	[0.856 ; 0.750] m	↑	+25%	+30%
Total Masse	6742.1 kg	↓	–3%	–4%
Unsprung Mass	[1130 ; 1000] kg	↑	+6%	+7%
I_{xx}	4225 kg m²	↓	7 kgm²	6 kgm²
I_{zz}	30000 kg m²	↓	40 kgm²	30 kgm²
T rear/2	0.915 m	↓	–2%	–3%
T front/2	1.003 m	↓	–3%	–4%
μ max (F_x/F_z)		—	+200%	—
τ max (F_y/F_z)		↑	+13%	+14%

The two values in [;] represent respectively the values of parameters for the front and rear axle.

K_p: Stiffness coefficient of pneumatic

K_s: Stiffness coefficient of suspension

K_b: Anti roll Stiffness coefficient

COG: Centre of gravity

I_{xx}, I_{yy}, I_{zz}: longitudinal, lateral and vertical inertia moments

μ max: longitudinal skid resistance

τ max: lateral skid resistance

L_1, L_2: Distances between axles and the COG.

From this table, we conclude that, around the rollover area, the most influencing parameters are: the centre of gravity height, the mass and the axle width. Then, damping coefficient, roll centre height and the lateral skid resistance.

The pneumatic stiffness coefficient, the longitudinal skid resistance and inertia moments have little influence.

3.3.2 Influence of Parameters variation with constant speed

Now, we make tests with variation constant speed of 54km/h (15m/s). The parameters are varying of about 5% or/and 10%.

The results are shown in the following table 4:

Table 4 : Parameters influence : constant speed

Parameters variation	LTR		Variation coefficients of LTR	
	Axle 1	Axle 2	Axle 1 (%)	Axle 2 (%)
Reference (0%)	0.666	0.771	0%	0%
K_p–5% K_p–10%	0.665 0.664	0.772 0.774	–0.1 –0.3	0.1 0.4
K_s–10%	0.665	0.777	–0.1	0.8
K_b–10% K_b+10%	0.657 0.673	0.763 0.778	–1.4 1.1	–1.0 0.9
h +5% h +10%	0.695 0.724	0.804 0.837	4.4 8.7	4.3 8.6
CO Roll + 5%	0.669	0.772	0.5	0.1

CO Roll +10%	0.672	0.772	0.9	0.1
Total Mass –5% Total Mass –10%	0.682 0.702	0.779 0.790	2.4 5.4	1.0 2.5
Unsprung Mass +5% Unsprung Mass +10%	0.675 0.685	0.778 0.785	1.4 2.9	0.9 1.8
I_{xx} –10%	0.666	0.771	~ 0	~ 0
I_{zz} –10%	0.666	0.771	~ 0	~ 0
T Axle 2 – 5% T Axle 2 – 10%	0.679 0.693	0.813 0.856	2.0 4.1	5.5 11.0
T Axle 1 – 5% T Axle 1 – 10%	0.688 0.712	0.775 0.780	3.3 6.9	0.5 1.2
μ max + 10% μ max – 10%	0.665 0.667	0.770 0.772	–0.1 0.1	–0.1 0.1
τ max +10%	0.666	0.772	0	0.1
ν+ 5%	0.724	0.830	8.7	7.7
β + 5%	0.703	0.809	5.6	4.9

The sign '+' of LTR corresponds to increase of rollover (the error of the obtained values is about 0.1%). We remark that the most influencing parameters are: steering angle, speed, the centre height of gravity, total mass, unsprung mass and the axle width.

The pneumatic and suspension springs have a little influence on LTR.

In the practical case, we have to know the exact values of parameters in order to make a best sensitivity study.

4 Conclusion

We study in this report, the influence of different parameters on the heavy vehicle dynamics and the rollover risk. First, we described the heavy vehicle model that we chose for this study. This is a simplified (but sufficient for this study) Ackermann model with three degrees of freedom. This model has been validated using PROSPER software simulator.

Many tests have been done with the model and with PROSPER. Some parameters variations are introduced in the model to show their effect on the dynamics (states) and on the rollover risks. We have seen that the variation of some parameters like centre height of gravity, Total mass, steering angle or skid resistance can affect seriously and sufficiently the dynamics of the heavy vehicle and cause its rollover. The other parameters like, stiffness coefficients and inertia have little influence.

These tests are done on the straight line and on the curvature with different speeds.

We have shown that on the curvature, the rollover limit speed is about 63 km/h. The wheels can take off but without rollover of the heavy vehicle. This rollover is effective when the speed reaches 68km/h.

We can with the developed method, calculate the limit speed on each vehicle trajectory.

We choose for our study the nominal values of parameters, done by PROSPER’s simulator. However, it’s important to verify the credibility of these values asking heavy vehicle constructors, manufacturers...

To study the rollover risk and develop a predictive system, it’s then very important to know exactly the nominal values of heavy vehicle parameters, if it’s possible. If it’s not the case, we have to identify online these parameters in order to take into account their variations in the rollover predictive system.

In the future, the same work can be done, on the truck semi-trailer model with much more degrees of freedom and parameters. In this model, the road profile, radius of curvature, skid resistance, longitudinal and lateral slop are considered.

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