ASSESSMENT OF VANS' BRAKING PERFORMANCES DEPENDING ON LOAD AND ROAD SURFACE CHARACTERISTICS




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ABSTRACT

European regulations are not as tight for Light Commercial Vehicles (LCVs, vans) as they are for trucks. Thus, the flow of vans has highly increased in the past years in the European Union, because of cost reduction, flexibility of driving time, routing and parking easiness, etc. However, many of these vans are operated for long distance freight transport with high overloads. Therefore, the risks of instability and longer braking distances are increased but not well known, as well as unfair competition in freight transport. This study aims to fil the lack of knowledge on the variations of vans' braking distances depending on the vehicle mass, (over)loads and tire-road friction performances. Numerical modeling, simulations by a truck behavior software (PROSPER) and in-situ tests are combined to address the problem. Some analytical computations first allow identifying the trend of the braking distances versus the gross vehicle mass and road friction conditions. Then, an analysis of real traffic data collected by WIM systems identifies the most frequent types of vans on current roads, and numerical simulations are performed with PROPSER software. This software provides extensive information regarding the vehicle behavior, which would be difficult to derive from complex equations with many influence parameters. The simulations allow assessing the effect of vehicle mass, location of gravity center, speed, and road friction coefficient, on vehicle braking performances, i.e. braking distance and wheel lockup status. Results show that all these factors have a combined and complex influence on the braking distance. Finally, field tests were conducted on a test track with an instrumented van to validate the model and simulation. Analyses of the experimental results prove the model's relevance. This study provides a background to improve vehicle braking performances and stability. It also justifies direct overload enforcement by WIM, to increase road safety.

1 INTRODUCTION

In France, the use of Light Commercial Vehicles (LCVs or vans) has skyrocketed in the last years for both short and long distance freight transport. A survey carried out by the French Parliament for the government [1] [2] revealed that the share (in t.km) of the freight transported by vans in France increased from 9.2% in 2000 to 13.6% in 2016. 24% of the 30,000 vans used for third party freight transport in France are operated by foreign companies, and almost 17% are doing cabotage. This comes from the more permissive regulations applied to these vehicles than to trucks, which make them highly competitive in a constrained economic context. Vans are neither subject to driving time limitations, nor to time or route access' bans. They are driven with standard car driving license with low cost drivers. Moreover, they are mostly operated with heavy overloads, up to 50 to 100%. The French Ministry in charge of Transports has committed the Université Gustave Eiffel and the Cerema to carry studies and trials on direct enforcement by high-speed WIM systems, and to develop, with the Legal Metrology, some specification and a frame to implement it. The Ministry required targeting the overloaded vans as well as the trucks. In the meantime, the directorate for road safety committed the Université Gustave Eiffel and the Cerema to investigate and report the effect of vans' overload and other parameters on their braking distances. This paper reports some outputs of this study, comprising software simulations and field tests.

Braking performances directly govern road safety by allowing both emergency manoeuvers (e.g. braking) and recovery manoeuvers (e.g. speed adaptation during cornering). Previous research works mainly focused on the development of braking models for road design purposes. However, a lack of knowledge remains about the influence of mass and of load distribution in vans, on their braking performances.

The axle and wheel load distribution and the height of the center of gravity depend on the gross vehicle mass, govern the vehicle stability and behavior, and have influence on the emergency braking distance. Therefore, overloads reduce vans' safety [3, 5, 6, 7].

This study first analyzes current traffic data provided by WIM systems to identify the types and characteristics of the most frequent vans. Then, a braking model including all the relevant parameters was calibrated on PROSPER software to perform numerical simulations. Finally, field trials carried out on a test track in Nantes with an instrumented van allowed checking and validating the simulation's results. The paper reports in-depth analysis of the gathered results.

2 METHODOLOGY

The methodology consists of computerized analysis methods, using Prosper software to simulate a van (Renault Master). The analysis of the van's dynamic behavior for different loads, speeds and road friction coefficients allows assessing the stopping distance.

The study mainly comprises two phases:

- Phase 1: analysis of real traffic data collected by WIM, development of a vehicle braking model and simulations based on a numerical software, in order to relate overloads with braking distances.
- Phase 2: building a test plan carried out on a test track with a van specifically instrumented for this project and results analysis to validate the model and the simulations.

The first phase of the study consists in [4]:

- Using a numerical software to estimate braking distances as a function of the vehicle mass. The braking distance highly or low depends on the mass, depending on the braking force limitation cause. The mass has a high influence if the limitation comes from the braking system capacity (and energy dissipation). This influence is much lower if the limitation comes from the friction capacity (max. horizontal force before slipping).
- WIM data providing vans' geometrical characteristics, axle loads and gross weight in the traffic flow, allow estimating the parameters of the most frequent vans to be used in the simulation software.
- Developing a numerical model of this van allowing the calculation of its braking behavior by the PROSPER simulation software.

- Simulating braking scenarios under various configurations (mass, load distribution, initial velocity, skid resistance), to evaluate the dynamic behavior of the vehicle and stopping distances.
- Identifying and quantifying the parameters directly or indirectly affecting the stopping distances of vans assessed by simulation.

The second phase of the study consists in:

- Instrumenting a real van with sensors, such as accelerometers, strain gauges…, mounted on its wheels and body.
- Running an extensive test plan on the test track located at Université Gustave Eiffel in Nantes, with various loads, initial velocities and skid resistance, on wet and dry pavement.
- Double-checking the test results across the simulation results of the phase 1.
- Re-calibrating the simulation model with the test results.

3 IDENTIFICATION OF MOST COMMON VAN TYPE BY WIM TRAFFIC DATA ANALYSIS

We analyzed WIM traffic data gathered on two highly trafficked sites, one located on a national road (RN4) and the other on a motorway (A6): on the A6 motorway, 117 days of data registered between June and September 2007, and on the RN4, 104 days registered between November 2007 and March 2008.

The information for each vehicle is:

- total length,
- wheelbase (front to rear axle),
- velocity,
- gross weight,
- axle loads.

The vans were identified and classified by an iterative procedure. The criteria used for the selection process are:

- 2-axles vehicles,
- total length between 4.8 m and 7.5 m,
- wheelbase between 1.8 m and 4.5 m

Indeed, criteria based on vehicles' length proved to be more effective than criteria based on vehicles' load.

Thus, 45,828 vans were found on the A64 and 47,126 on the RN4, representing respectively 3 and 5% of the vehicles. A significant proportion of these vans are overloaded between 3.5 t and 4.5 t, i.e. up to 30%. Their speed varied from 80 to 140 km/h with a distribution mode close to 110 km/h. The total length and wheelbase distributions are displayed on Figure 1.

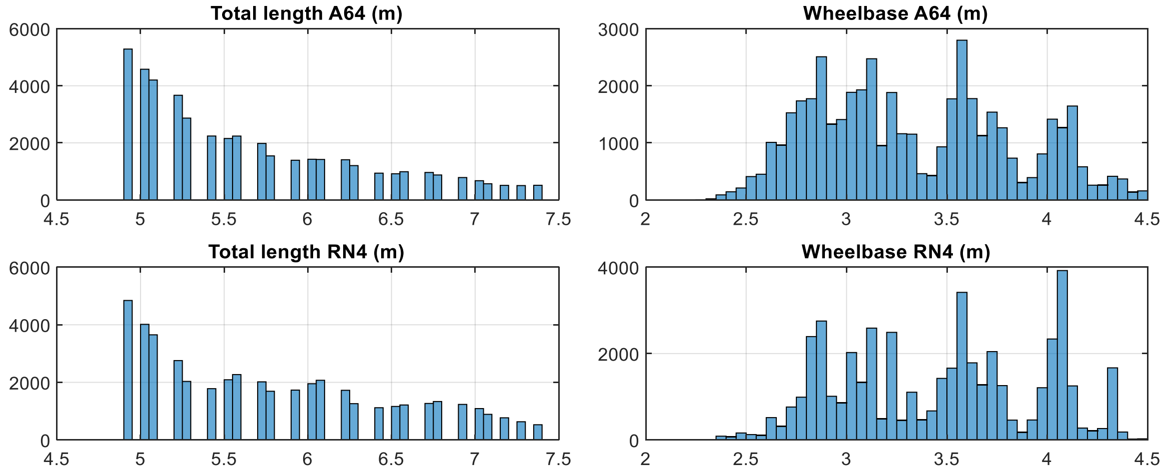


Figure 1: Total length and wheelbase distributions for vans in on A64 motorway and RN4 National road

Length distributions make it clear that the majority of the vans exhibit a total length ranging between 5 and 6m. The wheelbases appear to allow for defining at least three distinguishable groups (around 3m, 3.6 and 4.2m). Further analyses lead to sorting the selected vehicles into separate categories. Finally, the most represented van type is L2H2 model (i.e. 5.57 m length and 3.68 m wheelbase), which is used for the field tests.

4 SIMULATIONS AND EXPERIMENTAL RESULTS

To assess the van's braking performances depending on load and road characteristics, both simulations and field tests were performed.

Using a simulator is of paramount importance because some driving situations cases are either difficult or hazardous to realize experimentally, or require complex and expensive devices. On-site experiments must be cautiously prepared and carried out.

4.1 Simulation environment

Simulations were performed using the PROSPER software developed by the company OKTAL [8]. This advanced vehicle dynamics simulator was validated by several research laboratories and vehicle manufacturers. PROSPER uses a physical based model in a virtual environment closed to the real one on road (Figure 2).

This section presents the validation of the proposed van model against field tests results. The dimensions and weight of the van in the model are those of the Renault Master panel Van.

Figure 2: view of PROSPER interface software

4.2 Testing equipment

All field tests are performed with a Renault Master van, instrumented by the Cerema (Figure 3). The van was fitted with a high-resolution data acquisition device "VBOX 3i", using a GPS-based technology from Racelogic, with a sampling rate of 100 Hz. Van's data such as driver's commands, dynamic van response, van location, are collected by several sensors mounted either on the vehicle body or wheels (Figure 3). The velocity and acceleration are calculated from the location (traveled distance). The braking distance is evaluated with an accuracy of ±2 cm.

The VBOX Inertial Measurement Unit (IMU04) complements the main system (Figure 3). It uses three rotational rate sensors (yaw, pitch and roll) and a tri-axial accelerometer pack (X, Y and Z) working in the range ± 5 g. The IMU is connected directly to the VBOX 3i for simultaneous sampling. The signals are transferred to a laptop for further signal post-processing.

Figure 3: Instrumentation of the Renault Master van

Different loading configurations are implemented in this van (Figure 4), allowing to test different heights of the center of gravity. The van mass varies from 2.4 t to 5.5 t.

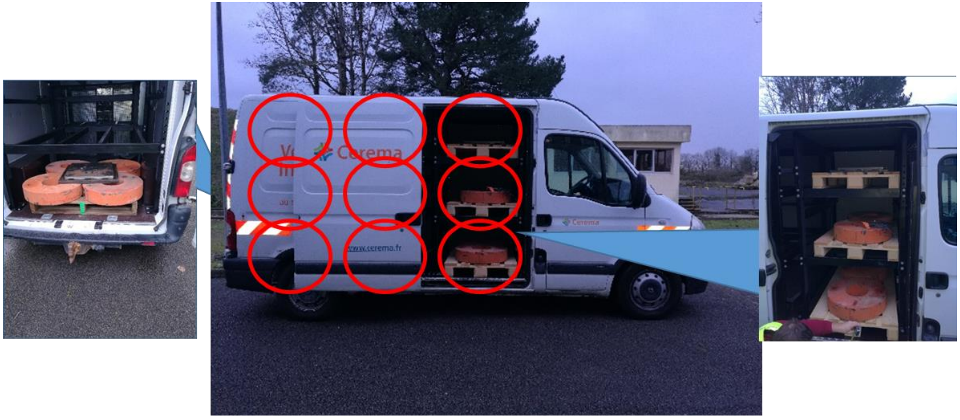


Figure 4: Loading conditions of the van

The tests were carried out on Université Gustave Eiffel test track (Figure 3 - left). The pavement surfaces on different locations are representative of the French road network: asphalt concrete, surface dressing, etc., incl. special surfacing: epoxy, painted surfaces, etc., all with different friction coefficients. The test track is flat and horizontal with a cross fall around 1.5%. Sprinklers can wet the track surface with varying water depths. The tests are performed on two tracks, named E1 and C1. E1 is a dense asphalt concrete 0/10 and C1 is a fine surface dressing. On dry surface, C1 exhibits a high level of friction whereas E1 exhibits an intermediate level. When wetting these two test tracks, E1 exhibits a low friction level and C1 a very low level of friction.

4.3 Simulations results

Simulation results are first used to validate the model of van against test data. The model parameters were adjusted to minimize the differences between experimental and simulation data.

Tests are performed both on wet and dry pavement surfaces. Figure 5 shows the same exponential decrease of the braking distance when the friction coefficient increases, with numerical simulations and on-site tests and at both speeds (50 and 80 km/h). Moreover, the braking distances are in the same order of magnitude. Therefore, it confirms the relevance of the model.

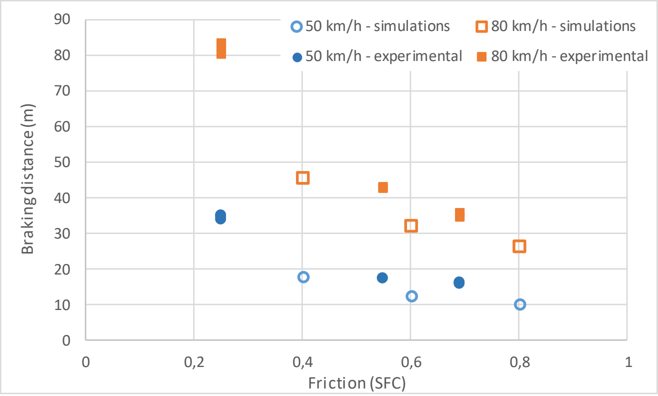
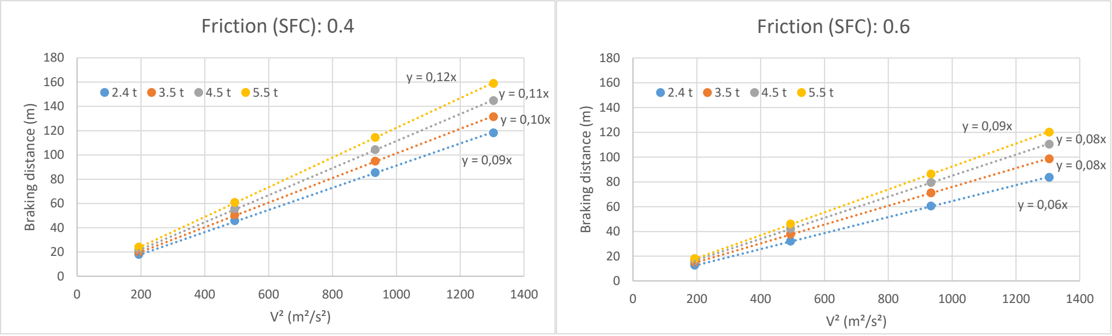


Figure 5: Comparison between experimental and simulated braking distances depending on friction (mass: 2.4 t)

Then the full simulation plan is carried out with four initial velocities (50, 80, 110 and 130 km/h) and four masses (2.4 t, 3.5 t, 4.5 t and 5.5 t). The 2.4 t mass corresponds to an empty van. The 3.5 t mass is the maximum authorized value. The two additional values correspond to app. 30% and 60% of overload. Three friction coefficients (SFC) are used representing low (0.4), intermediate (0.6) and high (0.8) skid resistance. Figure 6 shows all results obtained by simulation.

A linear relationship links braking distances and the speed squares for all masses. The slope of the straight lines increases with the vehicle mass whatever the friction coefficient.

Obviously, braking distances increase with initial velocity and mass. They vary from 18 to 159 m with low friction coefficient, and from 10 to 114 m for high friction coefficients.



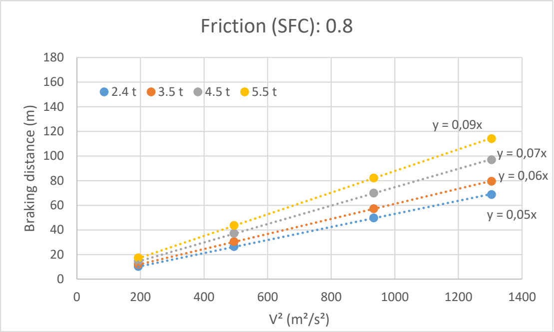


Figure 6: Braking distances depending on speed at different load and friction

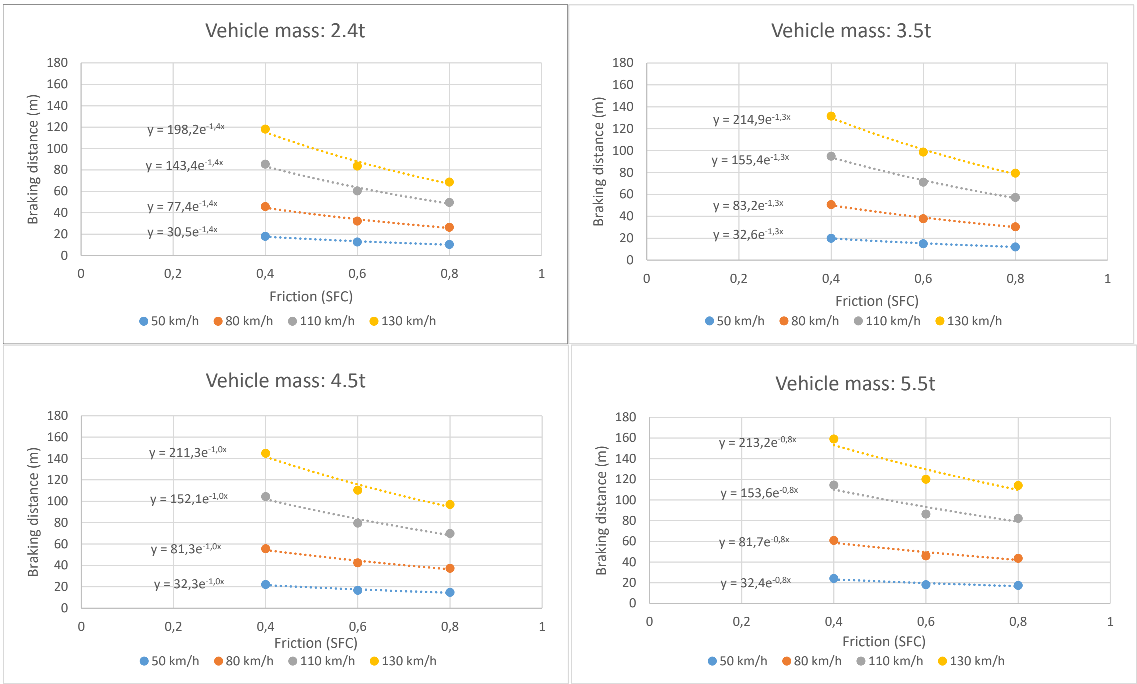


Figure 7: Braking distance variations with friction at different masses and initial velocities

Figure 7 displays the braking distances as functions of the friction coefficient, showing a decreasing exponential relationship. The multiplicative factor α in the exponent is constant for a given mass and decreases linearly as the mass increases. We thus find the following relation: α = -0.20 M + 1.93, where the mass M is expressed in metric tons.

4.4 Test Results

This section presents the results obtained on the two tracks (C1 and E1), both on dry surfaces first and then on wet surfaces.

Obviously, braking distances still increase with the initial velocity whatever the mass considered.

For low initial velocities, braking distances become very close whatever the vehicle mass. The straight lines linking the braking distances to the initial square velocities should converge all to 0, i.e. 0 m of braking distance at 0 km/h. and the surface conditions. It may be explained by the fact that braking forces stay proportional to the vertical forces in these conditions. Thus, braking distances are not dependent of the mass.

For higher initial velocities, braking distances tend to increase with the mass, and the variations become higher when the friction coefficient is high. This is explained by the fact that the braking power mobilized increases with the mass and friction coefficient. Thus, the braking forces Fx does not anymore increase proportionally to the vertical forces Fz (and mass) because the braking system reaches its maximum capacity. Therefore, the braking distances tend to increase proportionally to the kinetics energy of the van, i.e. the square of the initial velocity multiplied by the mass.

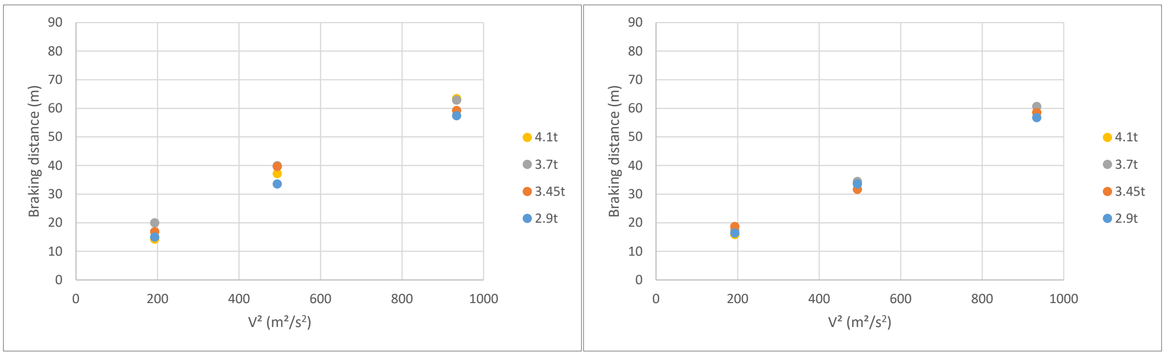


Figure 8: Braking distance for different masses on wet surfaces C1(a)- E1(b)

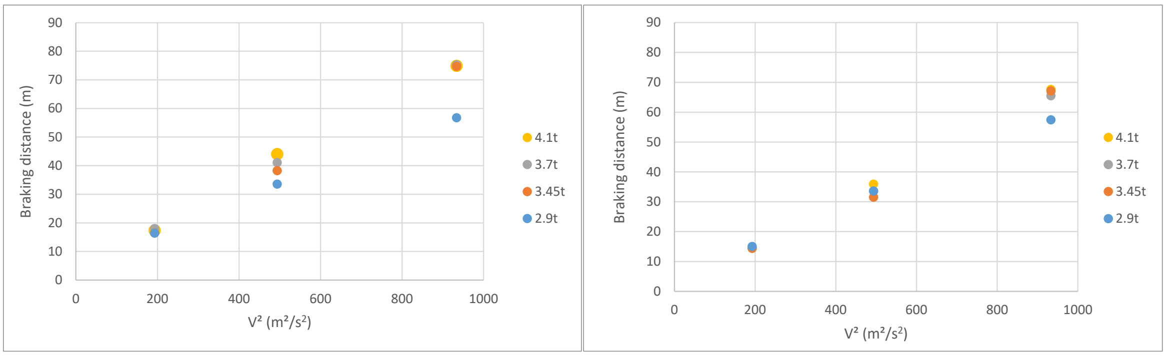


Figure 9: Braking distance for different masses on dry surfaces E1(a)- C1(b)

Figure 10 shows the evolution of the braking distance versus the initial velocity for the different surface conditions and for each loading case. For a mass of 2.4 t, braking distances measured on wet E1 are greater than those measured on the three other surfaces. It may prove that dry C1, wet C1 and dry E1 offer sufficient skid resistance to brake with the maximum braking system power (Fx_max), while on wet E1 the maximum skid resistance governs and Fx_max cannot be reached. However, E1 is a semi-coarse bituminous concrete representative of the coatings encountered on the French road network. The performances of these coatings are generally considered as correct.

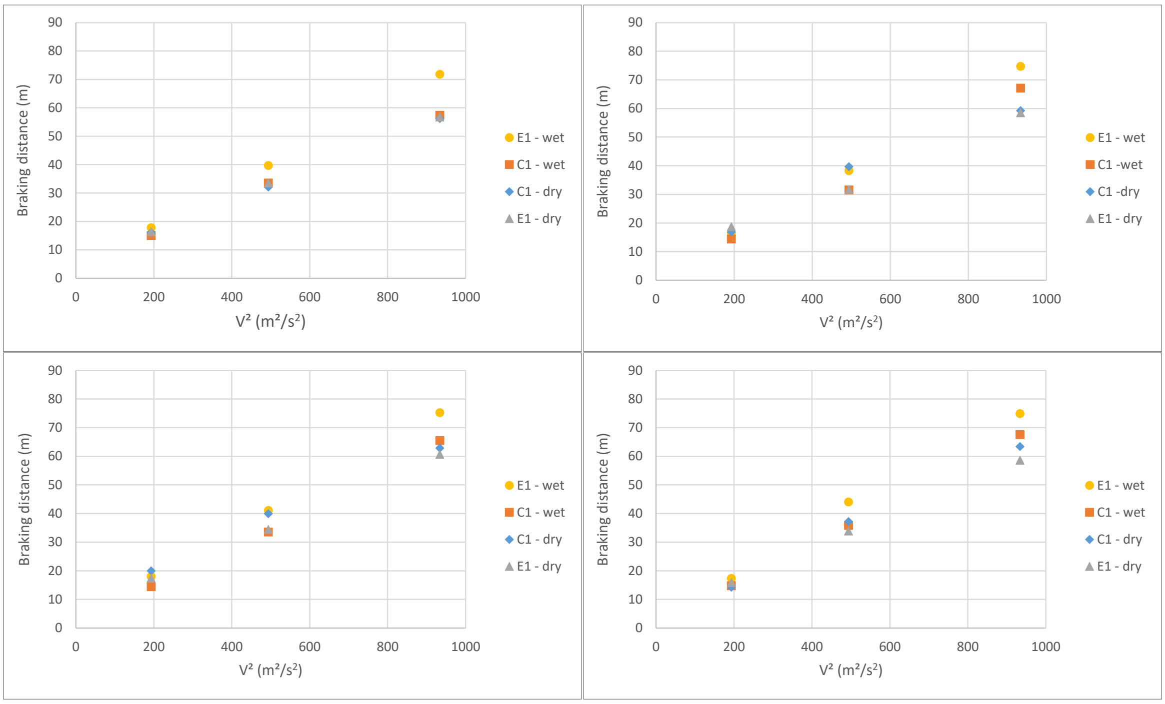


Figure 10: Braking distance with variation of a total mass of 2.9 t (a), 3.4 t (a), 3.7 t (c) and 4.1 t (d)

With masses of 3.45 t, 3.7 t and 4.1 t, braking distances measured at high speed (> 80 km/h) and on wet surfaces are greater than those measured on dry roads. Therefore, for total masses above the legal limit, the surface condition has a significant impact on the braking distances when traveling at high speed (> 80 km/h). The average braking distance increases by 10 m at 80 km/h and 20 m at 110 km/h.

Experimental results (Figure 11) show that at 50 km/h, the braking distances are similar regardless of the surface or load condition. Thus, the mass has almost no influence at low speed. Reversely at 80 km/h and 110 km/h, the mass begins to have an influence on the braking distance, which increases above 3.5 t. The phenomenon is even higher on wet surfaces.

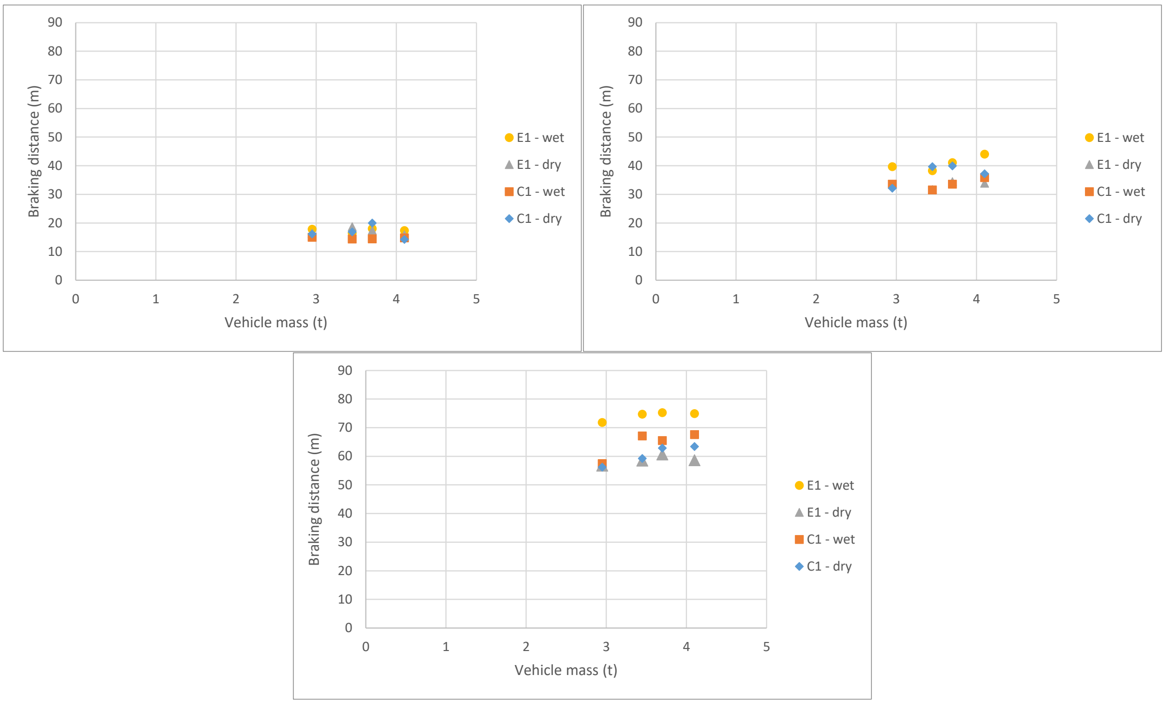


Figure 11: Braking distances at 50 (a), 80 (b) and 110 km/h (c) on various surface conditions

5 CONCLUSION

In France, the use of vans has strongly increased for both short and long-distance freight transport. Most of these vans are operated with heavy overloads, up to 50 to 100%. Thus, the directorate for road safety committed the Université Gustave Eiffel and the Cerema to investigate and report the effect of vans' overload and other parameters on their braking distances. Indeed, braking performances directly govern road safety by allowing both emergency manoeuvers (e.g. braking) and recovery manoeuvers (e.g. speed adaptation during cornering). This study was performed by combining numerical simulations and field trials on a test track with an instrumented van. The main factors influencing the braking distance on dry and wet pavement were identified and quantified.

First, an increase of the braking distances with speed is observed. For low initial velocities, braking distances appear almost not dependent from the mass due to the fact that braking forces stay proportional to the vertical forces in these conditions. For higher initial velocities, braking distances tend to increase with the mass, and the variations become higher when the friction coefficient is high. In these conditions, braking forces Fx does not anymore increases proportionally to the vertical forces Fz (and mass) because the braking system reaches its maximum capacity. Therefore, the braking distances tend to increase proportionally to the kinetics energy of the van.

Then, braking distances increase when the pavement surfaces exhibit low level of performances. This phenomenon is accentuated with high mass values (> 3.5t) at high velocity (> 80 km/h). The average braking distance increases by 10 m at 80 km/h and 20 m at 110 km/h between dry and wet surface conditions. These observations provide some background and justification to implement a direct enforcement of overloads policy in France in view of increasing the road safety related to vans' traffic.

6 ACKNOLEDGEMENT

The authors thank the French Delegation for Road Safety (DSR) for funding this research project and for their support during the COVID-19 crisis. They also thanks Sebastien Buisson, Angélique Guilloux and Samuel Louis for the preparation and realization of field tests.

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