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Weighing Technology for Laden and Unladen Light Commercial Vehicles

An on-board weighing system counteracts truck overloading. This benefits road safety and the environment, protects the roads and serves to ensure fair competition. Streparava presents its so-called OBWE system with suspension travel sensors, which uses a combined strategy to reliably determine the loading and load distribution in the vehicle in just a few seconds and with an accuracy of ±5%. The vehicle mass is calculated on the basis of an algorithm.

Overloading of trucks is a significant problem in the freight forwarding industry. A relatively large number of infringements of the law is related to weights of vehicles. On average, one in three vehicles checked is overloaded. These excess loads often exceed the gross vehicle weight rating by 10 or even 20 %. Overloading has a negative impact on the environment due to the pollutant emissions and the energy demand that increase with the weight of the vehicle. Overloaded vehicles lead to all sorts of negative issues, for example related to road safety, driver's safety, as well as road, bridge and environment degradation.

Due to these topics, the governments are working on legislation in order to prevent any infringements. The EU for example has already define a proposal [1]. However, different stakeholders have different perspectives and hence have different requirements for compliance with the weight limits. Public authorities must consider how to improve the overall goals they want to achieve. They want to reduce maintenance cost for road infrastructure, decrease environmental impact from road transport, improve road safety, and achieve a more efficient use of the road transport system.

Freight forwarding companies want to move goods in an efficient way – without being burdened by administration, paperwork formalities and frequent stops for compliance checks by authorities. In general, freight forwarding companies are also interested in fair competition, which includes that regulatory requirements are enforced and prosecuted equally for all actors in the market.

Vehicle manufacturers want to make money by providing their customers

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with highly functional, productivity enhancing and distinctive products. And professional drivers want to conduct their profession under safe and comfort conditions in their cabin and on the road. There are two different technical solutions in order to protect vehicles against overloading:
- Weigh in Motion (WIM)
- On-board Weighing (OBW).

The systems of the first solution need to be integrated into the road infrastructure. Depending on accuracy requirements, these systems are costly and require periodic maintenance. A large number of WIM systems need to be installed in order to support a high compliance-check density.

In contrast, OBW systems are fitted into the vehicles, rather than to infrastructure. They enable the weight data to be communicated at any time from a moving vehicle to the checkpoint or authority carrying out roadside inspections, to the driver or to other systems to vehicle fleet management.

ON-BOARD WEIGHING SYSTEM WITH DATA FUSION

Streparava has developed an innovative OBW solution, called Onboard Weighing Equipment (OBWE) [2], which is able to determine the actual vehicle weight (thus the gross vehicle mass) and the load distribution on each axle and each corner of the vehicle. The algorithm of the OBWE works with a data fusion approach. This means, it is able to mix and correlate information collected from the vehicle's CAN bus with the data provided by the installed sensors, **FIGURE 1**, and the driving conditions in order to provide the vehicle load information. The system is specifically designed for light commercial vehicles like transporters and minibuses, but modular and suitable for different vehicle like light commercial vehicles, heavy-duty trucks and other vehicle types. The new OBWE system is a step forward compared to current systems, which are significantly less accurate because, for example, they can only differentiate whether the vehicle is fully loaded or empty. They are not as accurate as the OBWE from the company Streparava.

In addition, the system allows to evaluate the truck's center-of-gravity position. The weighing system is mainly intended for vehicle manufacturers, but its design also assures the easy integration on existing vehicles as an aftermarket kit.

LAYOUT AND CONFIGURATION

The OBWE is composed by the following components, **FIGURE 2**:
- suspension-travel and/or air-spring pressure sensors integrated on each vehicle corner
- Electronic Control Unit (ECU) that collects and elaborates the signal data provided by the different sources
- Inertial Measurement Unit (IMU) installed in the chassis and integrated into the ECU
- calculation algorithm that is flashed into the ECU.

The suspension travel sensors are used to detect the relative position between wheel center and chassis (at each vehicle

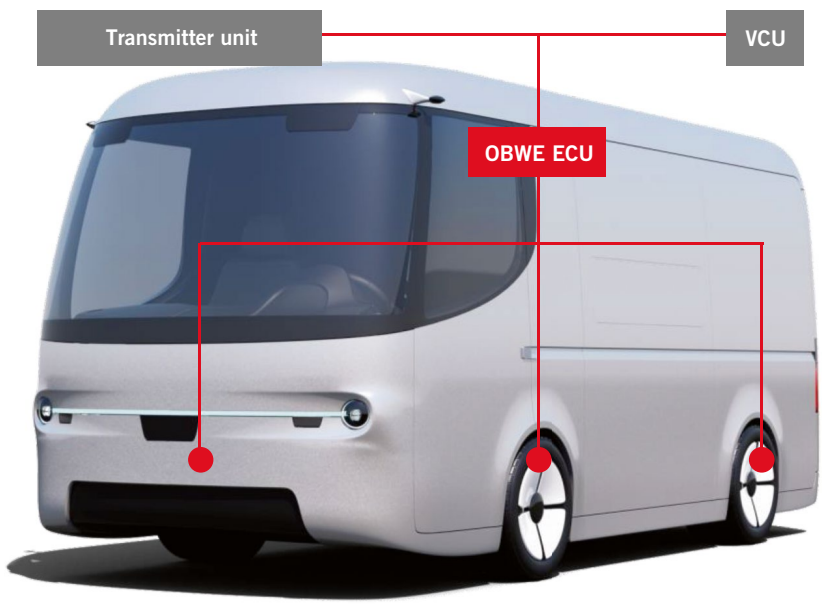


FIGURE 1 Block diagram of the OBWE onboard weighing system from Streparava: positions of the suspension travel sensors on the wheels and of the IMU inside the vehicle (red points) as well as their communication connections with the Vehicle Control Unit (VCU) and the transmitter unit (© Arand | Getty Images | iStock | Streparava S. p. A.)

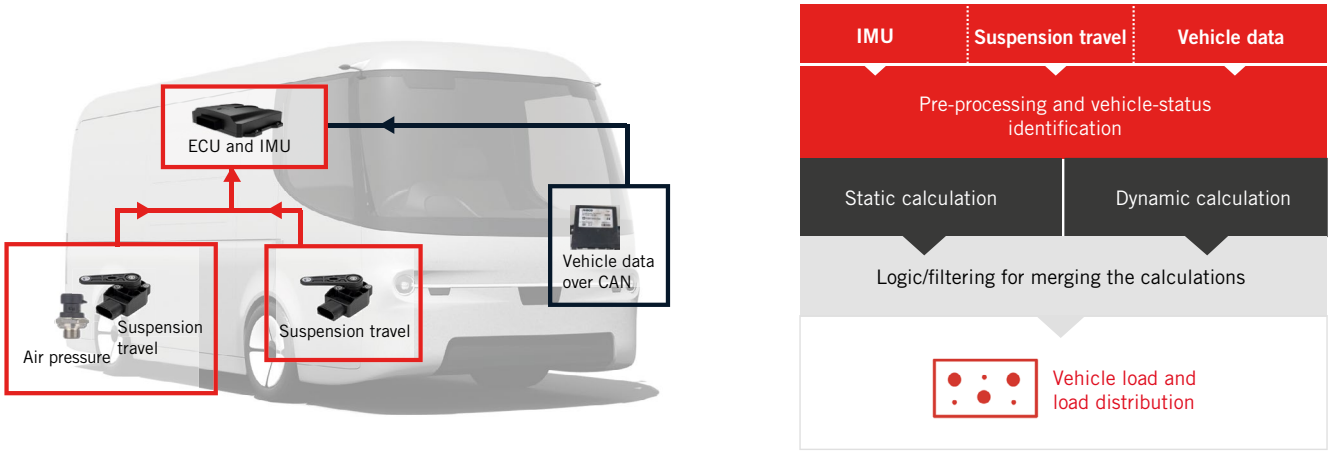


FIGURE 2 System layout: hardware components of the on-board weighing system OBWE (left, in red) and weight calculation process flow (right) (© Arand | Getty Images | iStock | Streparava S. p. A.)

corner). In case of an air suspension, the pressure sensors monitor the air springs. The IMU is fundamental to detect the status static/dynamic of the vehicle, and it has to be mounted into the chassis. It serves to detect roll, pitch, and yaw angles as well as accelerations at the chassis. The ECU collects sensor information and CAN bus data (for example vehicle speed, transmission gear, and brake actuation). All this data is processed as part of a data fusion and returned – usually to the vehicle CAN bus.

ALGORITHM INTEGRATION

The algorithm of the on-board weighing system is composed by different modules, **FIGURE 3**. For the signal processing module, the data provided by the sensors and the vehicle CAN bus is filtered, compared, and synchronized. The subsequent preparation steps are optimized on this basis. The driving maneuver check module analyzes the input data provided by the signal processing module, it is able to identify the status of the vehicle, after which the next evaluation step is activated or not. Only the maneuvers that permits to have reliable weight measurements are selected. That means, only the data related to specific driving conditions will be elaborated (no brake condition, acceleration lower than a threshold value, slope/incline lower than a threshold value and others).

The relevant spring parameters are defined in the suspension properties module with Look-up Tables (LUTs). The vehicle mass and the mass distribution are calculated through embedded LUTs that correlate the wheel suspension travel and load on the ground. The output information is provided to the next module. Finally in the calculation stabilizer module, it performs a data post processing before validating the output information. Not single data but a data cluster is used to define the output information.

A preliminary evaluation of the gross vehicle mass is available even when the vehicle is stationary. But the measurement reliability is limited due to friction, hysteresis and deformation of the overall parts.

During driving, the algorithm logic implemented into the ECU detects the vehicle's dynamic status, and identifies the selected maneuvers. It filters out the phenomenon described and generates an

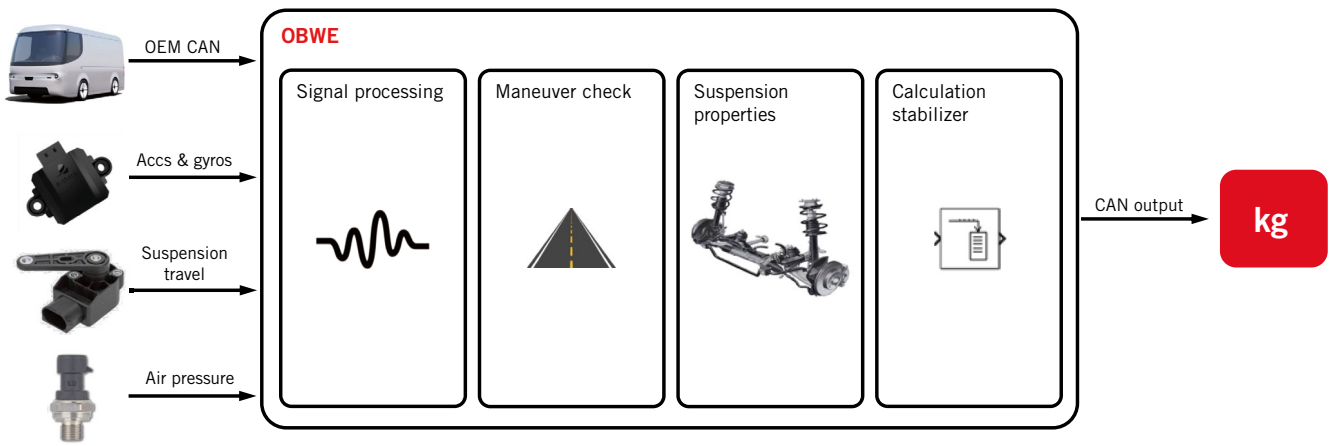
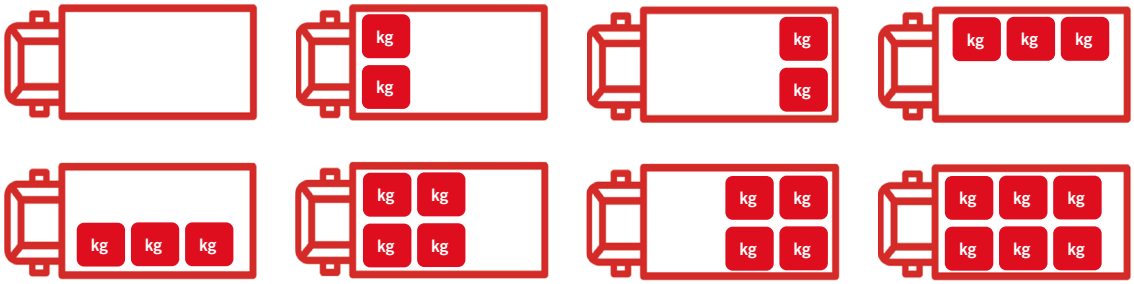


FIGURE 3 Algorithm structure for the OBWE on-board weighing system with its different modules (Accs & gyros: acceleration sensors and gyroscopic devices (yaw-rate sensors)) (© Arand | Getty Images | iStock | Streparava S. p. A.)



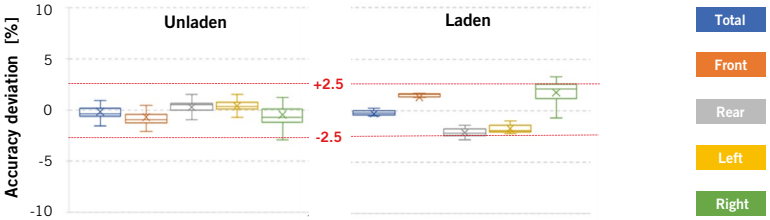


FIGURE 4 Reliability of load calculation: different possible load distributions in the load compartment (top) and accuracy of load calculation for light commercial vehicles with two axles (laden and unladen) regarding the gross vehicle mass (total, blue), front axle (orange), rear axle (grey), left side (yellow) and right side (green) (bottom) (© Streparava S. p. A.)

optimized mass related measurement within less than 10 s.

TESTING AND VALIDATION

In order to prove the performance of the system and the reliability of the load calculation, a lot of tests with different suspension configurations and different load distributions, **FIGURE 4**, were performed. Mileage tests, **FIGURE 5**, with various loads were carried out with good results. As can be seen, the accuracy deviation was almost never higher than ±2.5 %, not only with fully laden vehicle, but also with unladen vehicle. This exceeds what is required by the (EU) 2019/1213 Implementing Regulation of ±5 % at 90 % of gross vehicle mass rating [1]. The Streparava on-board weighing system has a resolution of 10 kg with a

sample rate of 10 ms and generates a first calculation available in 10 s.

With the same accuracy as reported before, the system is able to calculate also the load on each vehicle corner. With a good modelling of the suspension elements (springs, bump stops, dampers, and anti-roll bars), the vehicle load and the load distribution in the vehicle can be calculated with a good accuracy independently from load distribution, maneuvers, and drive style.

The system identifies the specific maneuvers, filtering load unbalancing due to road slopes and chassis acceleration during the ride. As a result, OBWE is also able to identify if any load changed its position during driving. Compared to other solutions, Streparava's on-board weighing system can be easily integrated into any suspension system.

ACTIVATED FEATURES

Other onboard weighing systems available on the market use completely different strategies to the OBWE, are based on more complex vehicle modeling and generally do not work reliably enough - either because of varying physical and vehicle conditions or because the systems only use strain gauges or similar and the suspension characterization must therefore be specified in great detail. In contrast, the OBWE uses a combined strategy in which the vehicle dynamics model is only used to select the conditions, under which a reliable measurement can be expected.

Instead of striving to model all of the vehicle's driving maneuvers in order to be able to calculate the weight at any time, the approach is opposite: continuous checks whereby the selection is only made if the model is sufficiently reliable.

The weighing system provides the load information via the CAN bus. In addition, also load distribution data and coordinates of the center of gravity (x, y, z) are available. This data could be used by other vehicle systems as a basis for features such as the following.

Tire pressure monitoring is enhanced so that tire pressure recommendations can be given depending on the load on the individual tire. The mass and its distribution information can be used to automatically define the target value torque for an adaptive retarder. In the event of uneven load distribution right/left, the driver can be warned of potential vehicle drift and/or uneven wear of brakes and tires by a monitoring of the mass distribution. The mass distribution data can be used to implement different strategies for adaptive electronic brake force distribution. This allows the rear axle share of the overall vehicle handling to be optimized.

The height of the vehicle's center of gravity can be calculated and the driver warned if there is a risk of overturning. For fleet managers, payload optimization is possible for the entire fleet. OEMs can create a database of mission profiles with load, strain and mission profile data from actual missions.

FUTURE IMPROVEMENTS

To upgrade the range of functions and to monitor the performance of the weighing system, a watchdog algorithm will be integrated. Using the vehicle CAN bus data collected by the system, with machine learning, the suspension stiffness could be calculated. This calculation would require quite more time than the time for the load calculation (several minutes instead of just a few seconds). But, during the operation time of the vehicle, the calculated stiffness could be used to validate and update the LUT data set in the software. Through this watchdog feature, it will be possible to monitor the status of the on-board weighing system identifying any drift or suspension tampering.

This approach could not be used as alternative to the main algorithm because the accuracy and the time response of it are not comparable. But it would be helpful to identify any discrepancies due to the aging of the suspension system for example. Using all the data collected with an AI approach, it is possible to realize different features. Furthermore, an auto calibration procedure will be integrated.

SUMMARY

In general, the OBWE on-board weighing system from Streparava enables warnings to be issued if the axle weight or respectively the gross vehicle mass rating is exceeded, if front/rear load an

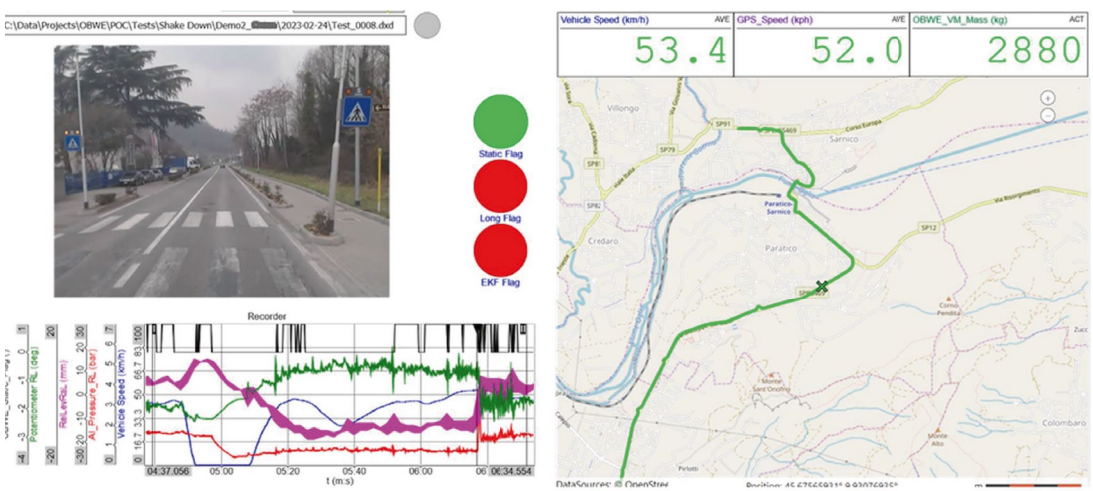


FIGURE 5 Mileage test: screenshots as examples of the user interface utilized during the validation of the test system for the on-board weighing system (© Streparava S. p. A.)

unbalancing occurs, and if the payload capacity must be maximized. In addition, a reduction in tire wear and maintenance need is possible. The added value of the system can be summarized as follows. Pollutant emissions to the environment could be limited by preventing overload condition and optimizing the load distribution on the vehicle. Vehicle safety is increased because the vehicle cannot be overloaded (which improves braking behavior); and the vehicle cannot overturn due to an uneven load distribution. The system can be easily integrated into a vehicle.

The system can be used flexibly and is therefore suitable for different suspension configurations. Weight calculation is accurate and robust over the complete load range. The weighing system can also calculate the coordinates of the center of gravity of the vehicle; this information could enable additional features where applicable. The on-board watchdog feature can detect tampering or anomalies of the suspension system. The information related to load and load distribution enables the definition of an accurate plan for vehicle's predictive maintenance.

REFERENCES

[1] European Union (ed.): Commission Implementing Regulation (EU) 2019/1213 of 12 July 2019. Online: http://data.europa.eu/eli/reg_impl/2019/1213/oj, access: February 27, 2024

[2] PCT Application No. PCT/IB2023/058225: Method for calculating the mass of a vehicle and system for calculating the mass of said vehicle. August 2023

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