CASE STUDY: MADRID REGIONAL TRANSPORT AUTHORITY (CRTM)

ABOUT TECHNET

Technet is a Spanish Company founded in 2007, devoted to the analysis of real driving emissions from road traffic. Our services are aimed at creating efficient mobility policies, which result in reduced emissions, increased energy efficiency and lower exploitation costs.

Furthermore, Technet is the only laboratory in the world accredited according to ISO17025 Standard for the remote measurement of real traffic emissions. This certification guarantees: (i) accuracy and reliability of data, and (ii) Technet´s technical competency.

For all our services, we use RSD (Remote Sensing Device) technology, which is capable of remotely measuring all gaseous pollutants (CO, CO_2, HC, NO_x) and particulate matter (PM) from road traffic, without the need for the vehicles to stop. It is a non-intrusive technology, and emission values are recorded instantly (≤1s) and associated to a picture of the license plate.

Our experience includes case studies for both public administrations (City Councils of most representative Spanish cities, Spanish Traffic Authority, Spanish Ministry of Environment…) and private companies (Mahou-San Miguel, Heineken, Repsol…).

Our efforts on Sustainable Mobility have led to the award of several prizes by the Spanish Ministry of Environment and Madrid City Council.

Furthermore, throughout these years, we have gained respect and recognition among public administrations in Spain, as proved by the inclusion of RSD technology in the National Air Plan 2013-2016 (Spanish Ministry of Environment).

Within this context, Technet currently works in close cooperation with the Spanish Ministry of Environment for the creation of national legislation for the implementation of RSD as an effective tool to greatly reduce traffic emissions and improve air quality. In fact, the law is already under public consultation (http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/participacion-publica/PP_2013_Proyecto_RD_emisiones_vehiculos.aspx) , and its publication is previewed for early 2014.

FLEET AUDITS: WHAT ARE THEY?

Through application of RSD technology, real emission data are available for all circulating vehicles, and hence a full characterization of the fleet in terms of emissions and fuel consumption is possible. With this data at hand, an efficient policy can be custom-designed in order to control and reduce emissions and substantially decrease fuel consumption.

These audits are based on the principle that malfunctioning vehicles not only emit more, but their faults are also the cause of excessive fuel consumption. Therefore, by detecting pollutants in vehicle´s exhaust plumes, it is possible to identify malfunctioning vehicles and quantify the loss in energy efficiency for each vehicle.

Among the numerous projects that Technet has carried out, we should highlight those executed for Madrid Regional Transport Authority (CRTM), Madrid Municipal Transport Company (EMT), and Barcelona Metropolitan Transportation (TMB).

THE “CRTM” RPOJECT

General Description

In 2009, a fleet audit was executed for Madrid Regional Transport Authority (CRTM). In just two working weeks, almost the entire fleet was audited without interrupting the daily operations.

The data was cross referenced with the technical specifications of each vehicle and statistically analysed.

Project design and data collection

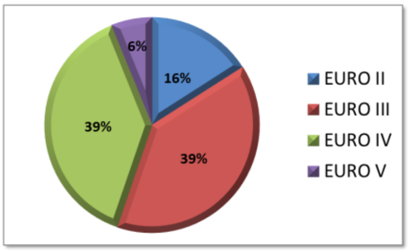
In the first phase, the main fleet characteristics were analysed in order to determine the optimal deployment points and measurement periods that would lead to registration of the highest number of records and major portion of the fleet within the shortest time.

One RSD unit was alternately deployed at 6 strategic points within the largest inter-city bus stations in Madrid. In just two working weeks, 1,800 emission records, corresponding to around 480 unique license plates, were obtained. These data was introduced in a specialized database, cross referenced with technical specifications (provided by Madrid Regional Transport Authority) and statistically analysed.

Characterization of the Fleet

All audited vehicles within the fleet corresponded to inter-city buses, with diesel engines between 10,000 cc and 12,000 cc and with the following distribution by age and technology:

Euro Standard	Nr. of Vehicles
EURO II	76
EURO III	187
EURO IV	184
EURO V	29
Total	**476**



Fleet distribution according to Euro Standard

Analysis of Fleet´s emissions

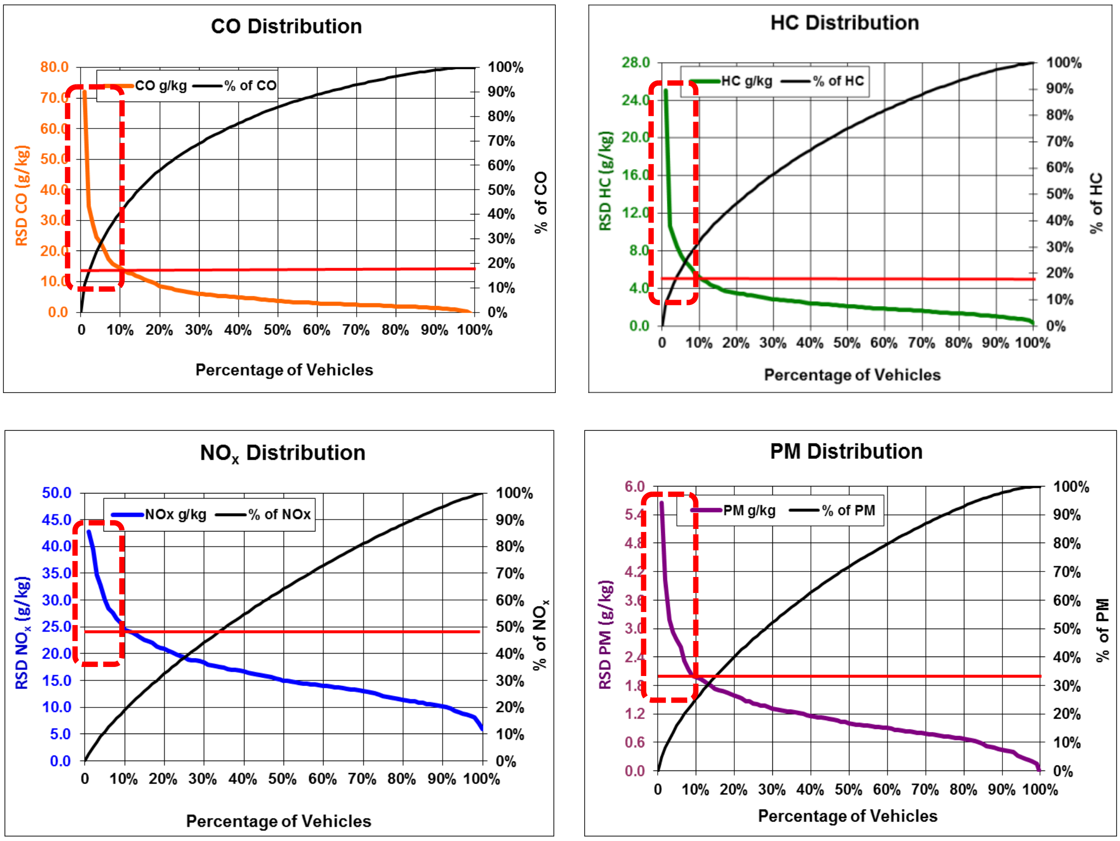
After the fleet was characterized, emission values for each vehicle were calculated. The table below summarizes the average emission values for each Euro Standard category (values are expressed as the median for each category, in order to avoid the distortion caused in the arithmetic average by high emitting vehicles).

Euro STD	CO (g/Kg)	HC (g/Kg)	NO_X (g/Kg)	PM (g/Kg)
EURO II	2.91	2.30	16.01	1.17
EURO III	4.08	2.12	14.73	1.12
EURO IV	3.61	2.10	14.37	0.93
EURO V	4.60	1.67	17.47	0.49
Fleet	**3.70**	**2.10**	**14.90**	**0.99**

Average emission values for each EuroStandard category

In the table above, a clear reduction of PM emission levels with improving Euro Standard technology is observed, whereas this is not the case for the rest of pollutants. Thus, HC emission levels do not decrease significantly with time, and for NO_x an increase in emission levels is observed. This phenomenon, the so-called "exchange effect", has been observed in numerous studies, and it always implies an increase in emission levels for the rest of pollutants due to the introduction of technologies to reduce PM emissions.

On the other hand, it is important to note that not all vehicles possess similar emission levels, as can be seen in the following charts (which show the emission distribution of the fleet). These graphs clearly show that a small portion of the fleet (left part, highlighted in red) is responsible for a large share of the aggregated emissions. These vehicles are defined as "high emitters"/"malfunctioning vehicles", and they present emission levels up to 10 times above the fleet average and energy efficiency losses of up to 20%.



Fleet emission distributions. In order to simplify the charts, the fleet was considered as a whole and extreme values from very high emitters were discarded in order to ease legibility.

From the above graphs, it is clearly deduced that just a 10% of vehicles, the so-called "high emitters" (H.E.), contribute excessively to the fleet´s global emissions, with shares of up to 41%:

	% CO_{total}	% HC_{total}	% $NO_{x\ total}$	% PM_{total}
H.E. (10%)	41%	32%	19%	25%

Contribution of H.E. to total emissions.

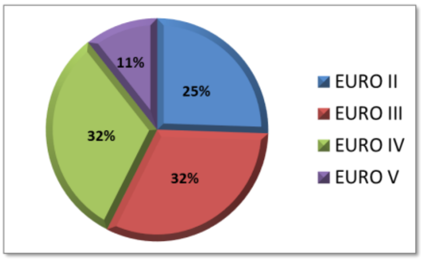
Identification of "malfunctioning vehicles" and implications to Energy Efficiency

After a preliminary analysis, it was agreed with the client to establish a threshold for energy efficiency corresponding to the 10% most inefficient/malfunctioning vehicles. This is, the 47 vehicles with worst energy rating were identified as "high emitters"/ "malfunctioning vehicles".

In order to evaluate the effects of repairing these vehicles through the most realistic and conservative approach possible, energy inefficiency (efficiency loss) calculations were performed from the emission “excesses” of the tagged vehicles. This “excesses” correspond to the difference between the emission value of each vehicle and the average emission for its Euro Standard category. The reasoning behind this procedure is to assume that the average value of emissions for each category is the one that every vehicle would present if this was properly maintained and functioning, and its energy efficiency was 100%.

Thus, after calculating the energy inefficiency associated to the mentioned emission excesses, the 47 most inefficient vehicles are distributed as follows:

Euro Standard	Nr. of H.E.
EURO II	12
EURO III	15
EURO IV	15
EURO V	5
Total	**47**



Distribution of H.E. according to Euro Standard category

According to the chartS above, we can clearly see that almost half of the most inefficient vehicles (43%) actually possess very modern engines (Euro IV and Euro V). This highlights the importance of maintaining a fleet audit program, which allows for the early identification and repair of malfunctioning vehicles, and hence increase in energy efficiency of the fleet.

As an example, the table below shows the emission values for one of the Euro V vehicles identified as “high emitter”.

License Plate	Nr. Reg.	Euro STD	Ex. CO	Ex. HC	Ex. NO_X	Ex. PM	Ineff. (%)
****GDK	3	EURO V	86,9	0	0	0,106	-6,9%

Real values of excess emissions in g/Kg fuel and energy efficiency loss (Inefficiency) for the most inefficient Euro V bus. Values expresed as the average of the 3 obtained records for this vehcile.

Finally, the “inefficiency” values were used to quantify annual savings in fuel according to fuel consumption data provided by the client. Savings were calculated for the audited portion of the fleet (25%) and then extended to the entire fleet:

Malfunctioning Buses	Annual savings (€)	% Audited	Total annual savings CRTM (€)
47	80,000 €	25%	**320,000 €**

Annual fuel savings according to 2010 prices and official consumption data provided by the client

Social and environmental impact of reducing emissions

Additionally, a calculation was performed in order to quantify the potential emission reduction that would be achieved through identification and repair of H.E., as well as the economic benefits associated to the improvement of Madrid´s air quality.

Audited fleet (Reduction/Ton)				Complete CRTM Fleet (Reduction/Ton)			
CO	HC	NO_x	PM	CO	HC	NO_x	PM
- 44.9	- 10.5	- 6.4	- 1.9	- 179.6	- 41.8	- 25.6	- 7.7
Total HE = - 63.7 Ton				**TOTAL Fleet = - 254.7 Ton**			

Annual reduction potential of emissions according to measured emission excesses for H.E.

In order to quantify the economic impact of these reductions, one must take into account the so-called “indirect costs”, which include environmental damage and hospital expenses related to poor air quality conditions.

Audited Fleet (25%)			Complete CRTM Fleet		
Pollutant	Red. (Ton)	Associated savings	Pollutant	Red. (Ton)	Associated savings
CO	44.9	67,350 €	CO	179.6	269,400 €
HC	10.5	157,500 €	HC	41.8	630,000 €
NO_x	6.4	96,000 €	NO_x	25.6	384,000 €
PM	1.9	190,000 €	PM	7.7	760,000 €
Total	63.7	510,850 €	**Total**	**254.7**	**2,043,400 €**

Quantification of savings related to emission reductions. Calculations based on estimations form Carl Moyer Project and studies from the EEA. Unitary costs: CO≡1,500 €/ton, HC≡15,000 €/ton, NO_x≡15,000 €/ton, PM≡100,000 €/ton.

Project Evaluation and main conclusions

- **A small number of vehicles (10%) present very high emission levels,** which represent a large share of global emissions (20-40%).
- **There is a clear relation between malfunctioning vehicles, high emission levels and energy inefficiency.**
- **One of the most efficient solutions for reducing fuel consumptions and minimizing operational costs** of public transport fleets consists on the identification and repair of these “high emitters”/“malfunctioning vehicles”.
- Apart from the immediate benefits derived from fuel consumption reductions (320,000 €), there are further benefits related to air quality improvement and reduction of government spending (2,043,400 €).
- RSD-based fleet audit programs constitute a quick and efficient method for the identification of malfunctioning vehicles within any type of fleet.
- Data collected in these studies are very useful for decision-making in order to optimize the operation of the audited fleets. Apart from increasing energy efficiency, they reduce the risk of breakdowns and accidents.

ANNEX I – Detailed methodology of Fleet Audits

Basic operation of Remote Sensing Technology

RSD (*Remote Sensing Devices*) uses absorption spectroscopy techniques in order to precisely measure all pollutants from vehicles exhaust. The devices possess a light source that continuously emits an IR/UV beam at specific wavelengths for the selective absorption by exhaust gases (HC, CO, CO_2, and NO).

RSD Deployment (from left to right): IR/UV source/detector, speed/acceleration sensor, digital camera

Once the light beam crosses the exhaust plume, the detector registers the corresponding changes in light intensity due to absorption of exhaust gases and particulate matter. These can be easily transformed into concentration ratios (pollutant/CO_2) through Lambert-Beer law.

Additionally, RSD are equipped with a laser sensor system that records speed and acceleration of the circulating vehicles while their emissions are measured. These parameters are extremely important, since they are used to calculate the engine´s load, which influences emission values. Thus, speed, acceleration and road slope are used for estimating the so-called "specific power" (VSP), which is then associated to each emission record. This allows discarding non-representative data, which are outside the optimal VSP range.

Finally, RSD are also equipped with a digital camera, which captures a picture of the license plate.

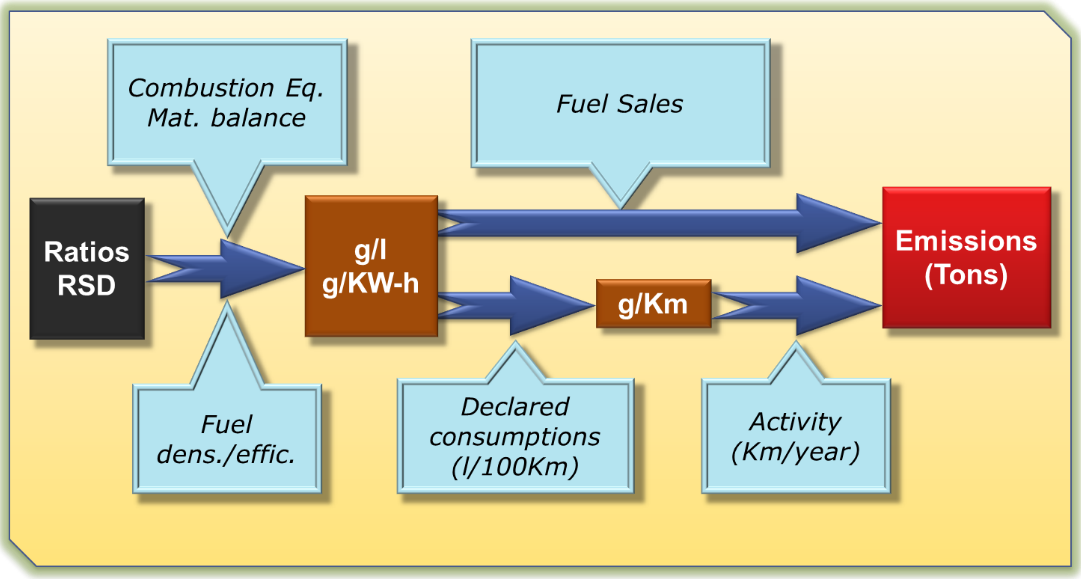
Hence, in less than one second, a complete record is obtained: vehicle emissions, kinetic data (speed and acceleration), and a picture of the license plate (from which an accurate identification of the vehicle and provision of its technical specifications will be obtained).

Data processing and conversion to representative units

As expressed before, RSD do not measure concentrations or absolute quantities of exhaust gases, since this is physically impossible due to the remote and non-intrusive nature of the technology. Instead, they report pollutant concentration ratios versus CO_2.

However, assuming the fact that the relations *pollutant/CO_2* are the same throughout the plume, these ratios can be used to obtain emission values in more significant units.

The chart below schematically shows each and every one of the transformations needed for obtaining representative emission values (All data processing is performed in an automatic and precise manner through specialized software that accompanies RSD).



The overall process implies several consecutive transformations:

- Using the fuel´s chemical combustion equation (in which hydrocarbons react with oxygen to render CO_2 and water) and applying material balance principles, ratios can be transformed into grams of pollutant per kilogram of burned fuel (**g/kg**).
- Then, using fuel density data, emissions can also be expressed as grams of pollutant per liter of burned fuel **(g/l)**.
- For the subsequent transformations, the technical specifications of each vehicle (fuel type, cubic capacity, age and incorporated technology, vehicle type, etc.) need to be incorporated into the model. This data are easily obtained through the picture of the license plate, received either from the clients themselves or from the traffic authorities; and are immediately incorporated to the RSD software. Furthermore, the database also includes extensive reference tables for all vehicle types, cubic capacities, weights, UNECE, fuel type, Euro Standard…

  For example, by applying official energy efficiency data, emission values can easily be transformed into **g/kWh**, which is the reference unit for heavy duty vehicles.

  Similarly, by applying declared fuel consumptions to each record, one can also estimate the grams of pollutant per traveled kilometer (**g/km**). This is probably the most significant emission value, since it allows for the creation of emission inventories for entire fleets (for which annual mileage is known), in which emission values are expressed as tons of emissions per year (**ton/year**).

Fuel consumption and estimation of Energy Efficiency

Conventional vehicles currently operate through combustion engines, in which a mixture of air/fuel is injected into the engine, and after a combustion process, the corresponding exhaust plume is generated. This implies that there is a direct relationship between the emitted pollutants and the efficiency of the engine (this is, fuel consumption).

In an ideal combustion process, all the fuel is burned and the exhaust plume should be exclusively composed of CO_2 and water vapor (H_2O). However, in the real world unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and elemental carbon particules ("soot" or PM) are also detected in the exhaust.

The production of polluting gases in inevitable due to the nature of the combustion engine itself (for example, lower temperatures in areas close to the combustion cylinder walls, causing heterogeneous combustion), and this is further enhanced by other factors such as changes in the air/fuel ratio, poor engine maintenance or other mechanical issues.

From all the above, it is clearly deduced that there is a direct relationship between exhaust emissions and energy efficiency. This is, the higher the emission values in the exhaust are, the further away from ideal engine conditions the vehicle is, and hence the greater energy inefficiency it has.

If the carbon balance is traced all the way from its source (fuel) to the output in the exhaust plume, it is possible to quantify the portion of fuel that is "wasted". Through very simple calculations, the amount of fuel that is emitted as HC, CO and PM can be transformed into percentage of "lost energy"/"inefficiency"/"efficiency loss".

The following equation shows the percentage of efficiency loss as a function of the detected grams of pollutant per kg of used fuel:

$$\text{Efficiency loss (\%)} = \frac{1.2 * PM + HC + \frac{CO}{1.25}}{10}$$

With this equation, energy inefficiency (%) values are calculated for each vehicle within the fleet, and then those which present the highest efficiency losses are identified as "high emitters"/"malfunctioning vehicles".