Use of Laser scanning, Remote Sensors & Traffic Data Collection, Drones & Mobile Application. MoEI Federal Highways network case study.

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Abstract –

Application of technologies as laser scanning, remote sensors, drones or mobile applications are playing a major role in changing the management procedures of maintenance and operation activities in the roads. Without scarifying the quality of the data, tasks can be performed in less time while maintaining the same level of accuracy of the outcomes and results.

Keywords –

Laser scanning; remote sensors and traffic data collection sensors; UAV (Unmanned Aerial Vehicles or drones) inspection; mobile application; assets management.

1 Introduction

The Ministry of Energy and Infrastructure (MoEI) is the arm of the Federal Government in the United Arab Emirates to plan, design, execute, operate and maintain the Federal roads Network in the five Northern Emirates (800Km center line, 1600Km carriageway and 3700Km lane of highways), *(figure 1)*

Figure 1. Federal Roads Configuration

Operation and maintenance of the roads is a cycle of various interconnected fields and specialties, being all of them interconnected and affecting each other.

By nature, that interconnection happens around numerous variables, and as a road network having hundreds or thousands of kilometers big amount of inputs for those variables are required, thus generating a big database.

UAE MoEIhas detected the need of a comprehensive system to manage and operate the maintenance activities with the highest efficiency. Developing an own assets management customized system to obtain, collect and process the related data of roads elements, intending to enlarge their life span and keep the level of service of some parameters within the suitable range.

The level of service for those established parameters are related to the sustainability aspects from which the MoEI is responsible for. [1]

These systems use the historical information contained in the database as a self-learning tool to enhance any analysis. Therefore, a good quality database will provide as well a good quality results through the modification and enhancement of the algorithms behind the calculations ensuring that self-learning process will also be improved.

The technologies that recently the MoEI has implemented within the assets management system are mentioned below as well as the reason of why were they chosen. [2]

1.1 Laser scanning (LiDAR)

The inventory of the elements within the right of way of the federal road is a requirement to perform the proper maintenance (it is impossible to asses a right maintenance either predictive or corrective if the elements to be maintained are unknown for the road owner). This knowledge is not only referred to "know" that the element exists; it is necessary to have some basic information which will allow the decision maker to choose the most appropriate method for intervention in order to preserve the assets, taking into consideration the reduction in time and effort reduction, and most importantly, ensure safety for the road users as well as the rest of the sustainability parameters. [3]

In the case of MoEI these pictures have been obtained since 2012 using a high-performance vehicle in which the pictures are taken and assembled every 2 meters composing frames of 10 meters length. The data collection can be achieved by using different cameras arrangement combined with a series of devices, which will relate the pictures with geographic positions (GPS, distanciometers and correlation of that information with the typical used road milestones used in the country, which in MoEI's case are the light-pole number (sequential numbers placed in each light-poles). [4]

Within those 10-meter images, those elements constituting the road assets will be assigned to the system through their corresponding position and type through a file where their information can be stored after collecting it to create the full roads environment (dimensions, properties, condition, camber, slope, radius of curvature, etc.).

Implementation of *LiDAR* (*Light Detection and Ranging*) will combine all the previously mentioned parameters by generating a cloud of points then creating a 3D environment. This cloud of points creates a 3D attributes for each point, therefore we can obtain the geometric characteristics, relating them to 360 degrees pictures and describe the elements contained in the network, one by one.

LiDAR used to collect this information is a TRIMBLE MX9 equipment with capacity of 1 million points per second acquired with an average vehicle speed of 80Km/h and a mesh density of 1,000 points per square meter, *(figure 2).*

Figure 2. LiDAR vehicle used for data collection

Data acquisition from this device will provide the following described information .

As mentioned previously, within the information related to the inventory is very important to have the type, location and properties of the elements contained within the road network, *(figure 3).*

Figure 3. Data Inventory tables correlated with the Cloud of points and images

The typical data collection for the road network using the conventional methods took around 4 weeks of continuous work, and is compelled to be done during the daytime (considering as well the position of the sun to ensure the quality of the images). The data collection for the same length using LiDAR took only 14 days (saving therefore approximately 50% of the time required before).

The use of the cloud of points, allow to obtain cross sections of different segments of the road as well as distances between two or more points, areas and volumes. The benefit of that will be described after.

1.1.1 3D model creation

Both technologies mentioned previously, have been able to inventory more than 30,000 elements. And the creation of the continuous 3D model for the roads network can be integrated with other applications, systems and models in a near future as the usage in BIM *(Building Information Models)* or modeling base mesh for future growths or expansion of the roads, *(figure 4).* [5]

Figure 4. Bridge 3D model from LiDAR data collection

1.2 Remote sensors

Within the Bridge Management System (BMS), the main objective of these system is to store information of the bridge that can identify it as a singular and unique unit and to relate to that unit the condition of the structure, assessed by an assessment condition index developed by the MoEI and the University of Sharjah [6], [7], [8]

That index, indicates the condition of the structure according with a scale, depends on any defect affecting durability, structural behavior or operation of the bridge *(figure 5).*

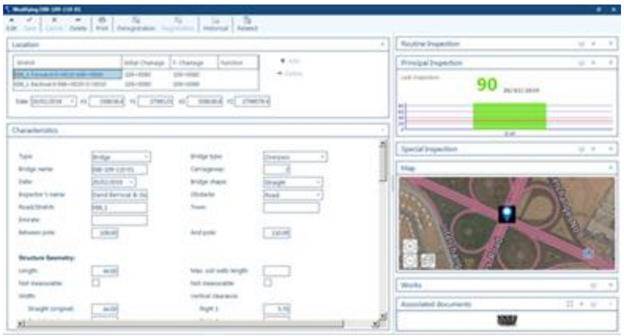

Figure 5. Bridge Assessment Condition Index within the Bridge Management System

These defects in each structure can be detected through *principal inspections* that are performed in a period of 3 years by specialized engineers. This period can however vary, depending on the severity of the structure's condition. shortened if the needs of the bridge advise to do that. These conditions can be determined by:

- Unpredicted events (as for example, a flood or high tide stream, or any other extraordinary climate event)

- Hit by a vehicle or any other external element which can compromise the safety of the structure
- To follow special conditions of defects found (for example follow up the evolution of any mechanic or chemical phenomenon)

Sensors will be assigned to some found defects minimizing the need of site inspections, especially when their behavior can affect the assessment condition index of the bridge.

Below, the descriptions of the technologies used in the bridge assessment condition are described, divided into 2 main categories: Mechanical and Chemical sensors.

The main advantage of the mentioned sensors is the continuous data collection without the need of physical inspections to measure the values for some important parameters. The values measured on site, will represent the evolution of the parameter in a specific time. Using sensors for data registry, will provide not only that date during sequential shorts periods of time, but also the historical information of that parameter. The connection between the sensors is achieved by using an interface at the MoEI.

1.2.1 Mechanical sensors

Some bridges have special mechanical conditions to be monitored. These conditions can appear because of the combination of the loads, materials properties, excess of stress or/and strain, or similar, *(figure 6).*

In some bridges of the network, there are some required mechanical aspects to be followed as described below.

- Crack monitoring in beams
- Bi-directional tilting in piers
- Stress and strain in beams and piers
- Temperature in the elements

The defects found in a bridge might disturb some of the mechanical responses of the structure. The measurement of the defect response will help not only to know the behavior of the element of the bridge where that defect is located, but as well, to understand why that happened, and to predict what will happen to similar elements under similar circumstances.

The monitored parameters can be measured not only individually during the analyzed period of time but as well, all can be co-related to find existing interconnections. The analysis of that behavior along the time can help as well to predict and perform some preventive actions and maintenance. [9]

Figure 6. Mechanical remote sensors for bridge data collection

2.2.2 Chemical sensors

In the particular case of the highways located in the northern emirates of UAE, the majority representing 97% of the bridges are made of concrete (as well pre-casted in situ or prestressed, or casted in situ), *(figure 7).*

Figure 7. Chemical remote sensors for bridge data collection

Some of those locations are adequate to develop corrosion (because of the presence of chlorides or carbonation), creating the worst scenario for the structure's durability. Affection can be accelerated by high temperatures and humidity, presence of salt in the soil in some locations and chlorides due to sea tides in others. [9], [10]

The main parameters reported by the sensors, installed within the concrete of elements of bridges in service are:

- pH evolution
- Temperature
- Humidity
- Chlorides content

The way to prevent and control this situation is to monitor the progress of the parameters creating and propagating corrosion and create the preventive measurements according to each bridge affected.

2.2.3 Traffic sensors

The third category for sensors installed in the network, are the Traffic Sensors, collection traffic data. These sensors are registering the number of vehicles, speed, type and some of them weight.

nother significant aspects are traffic characterization and users' driving behavior. As roads operator, knowing these aspects are crucial in order to help to prevent and attend accidents, moreover, try to predict them in the best possible way. This information also helps to understands the effect of traffic on bridges and pavements, thus do the proper design as new and rehabilitated assets. Moreover, these analysis helps other stakeholders in their fields such as Ministry of interior in procedures related to traffic and security, Ministry of Justice to improve or create laws related to traffic and Ministry of Health to prevent the resources dedicated to traffic accidents.

The traffic sensors are divided in two types, the Radars, which are utilized to measure the following group of parameters per lane and per direction in each road (22 out of 27), *(figure 8)*:

- Number of vehicles
- Type of the vehicles based on the length
- Speed

The remaining five (radars combined with piezo electric) in addition to the above parameters do register, *(figure 9)*:

- Gross weight of the vehicle
- Number of axles
- Weight per axle

Creation of enquiries about the traffic database will happen in special dashboards, which will provide in fast time the possibility to combine the information of different lanes and directions in a determined period of time, [11]. The enquiries parameters that can be calculated are:

- Average daily traffic
- Accumulated traffic
- Speed
- Intensity
- Occupancy
- Peak times (morning, mid-day and evening, time)
- Classification by length
- Classification by number of axels (using Federal Highway Administration criteria) (include here reference)
- Distribution on weight per axle per type
- Real time traffic conditions

Figure 8. Electromagnetic loops for traffic data collection

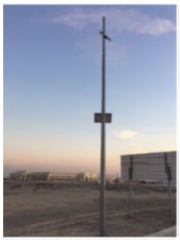

Figure 9. Radar traffic data collection

1.3 Unmanned Aerial Vehicles (Drones) inspection

Within the Bridge Management System MoEI included the bridge inspection by using UAV(drones), *(figure 10).*

The inspection helps to enhance the inspection time by:

- Inspection components which are difficult to reach by conventional resources
- Creation of 3D cloud of points
- Creation of 3D model

Drones to do the inspection are equipped by different devices such as camera, LiDAR and GPS.

Figure 10. Drone for LiDAR data collection

The inspection outcome is a report showing the pictures and defect detected. These reports include the location, evidence and the quantity of the damage registered. Once the defect is reported, it can be transferred to the BMS carrying along the possibility to modify the assessment condition index.

The data collected offer as well the possibility of creating a 3D model of the bridge using photogrammetry tools combined with the cloud of points.

1.4 Mobile application

One of the most important aspects in MoEI Roads Department is to keep active tasks related to the daily maintenance. The daily found incidents can’t be predicted and need to be attended as fast as possible, therefore the MoEI has implemented a Performnace Based Maintenance Contract based on KPI, (basically related to time response and quality). *(figure 11).*

Since this type of contracts are controlled by penalties applied to the main contractor if the deficiencies or incidents are not attended on time, it is necessary to improve the registration, control and monitoring of all the road elements. [12]

An inspectors' fleet checking continuously the roads, can register any defect allocated in the road through a mobile application, relating that report automatically to the location of the mobile device live.

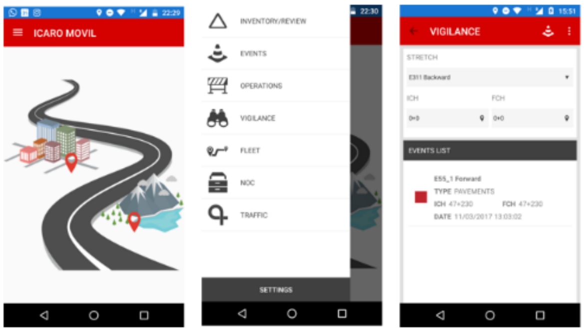

Fig 11. Mobile application for incidents management

The report will be uploaded in the database of the Assets Management System. In this way, MoEI as well is aware of the events pending to be finished and the available time before penalizing them, at the same time, allowing the contractor to register the closure of the report.

After, the inspectors are able to check and verify if the event was effectively closed and the quality level of service is achieved.

The mobile application shows the information contained in each report created by the road inspectors. And assuming that the reports can't have an "open" status for a longer period of 30 consecutive days without closing it by applying the corresponding maintenance, the reports for the last 30 days can be viewed in a list and in a map.

This mobile application as well allows to do the inspection of any other inventoried element in the road, including the bridges. The inspections will determine the assessment condition index of the elements that are in the same spot the inspector is.

2 Interrelation of all these technologies applied and benefit for the asset management in the Roads Department

All the previous described technologies can seem interesting from a technical point of view, individually.

However, a very important aspect is, how these technologies are interconnected amongst them and what benefit provide to the asset management of MoEI and how this benefit is can be noticed.

These properties and capabilities which are the base for the interrelation between them and the assets management, constitute significant aspects that will feed the specialized fields in the assets management tasks.

2.1 LiDAR (inventory and 3D model)

The inventory with LiDAR will feed the database of the mobile application and the inventory database for the main system for the Roads Department. The Road elements will be reflected in both and all the information as well as the assessment condition index can be modified and corrected by the user.

Moreover, the 3D models created during the process can merge with those 3D representations created by the *drones.*

3D models open possibilities to do a better analysis for specific road elements. For instance, if a structural/durability issue needs to be studied in a bridge, it will be easy to define the grid of this bridge and its elements, isolating it from the general cloud of points and exporting it to an 3D structural analysis software, *(figure 12).*

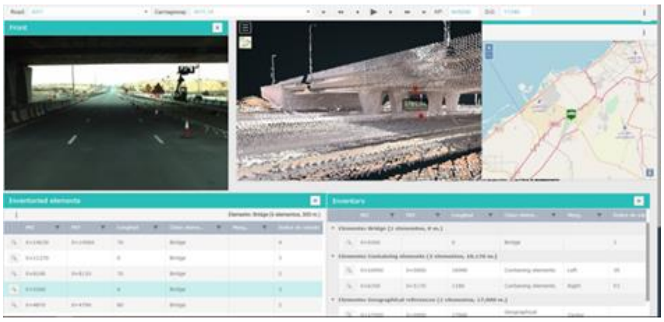

Figure 12. Cloud of points for post use in other applications

The importation of the cloud of points as a mesh to a conceptual design software for roads, used in widening or modification projects can provide with an initial high accuracy database for that project, without the need to collect more information with other methodologies, *(fig 13).*

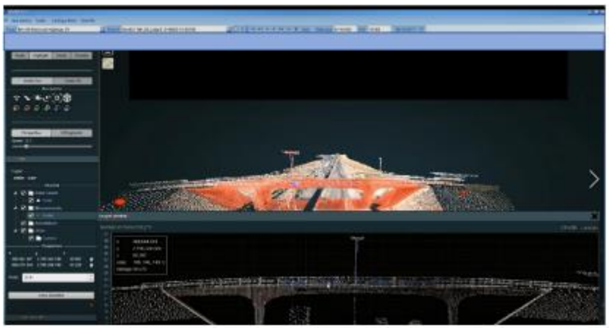

Fig 13. 3D model from LiDAR data. Creation of cross sections for post analysis in structural analysis

A very important use of this tool will be to define the contour conditions for an *Autonomous Driving Car* simulation (of different road parameters and their current condition to calibrate the possibility of autonomous vehicles to circulate within the network).

As well, this model will be very useful for the creation of High Definition Maps, which will be used by this type of technology which constitutes one of the main pillars on the development of the transportation sector in the coming 20 years in UAE, *(figure 14),* [13]

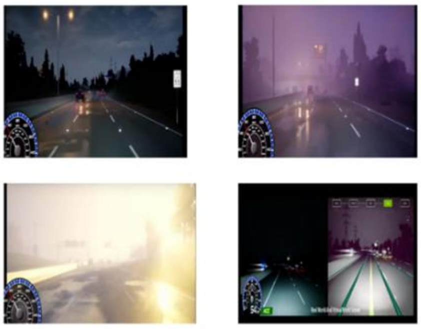

Figure 14. Autonomous vehicles simulation

2.2 Mechanical and chemical sensors

They provide a real valuable information related to problems (mechanical or chemical) which can influence the response of the bridge in different ways.

The inputs these sensors can have in order to modify the condition assessment index of the bridge are evident (is not the same case to have a “dead” shearing crack in a beam that notice that it is progressing, *(figure 15)*.

Figure 15. Bridge sensor’s platform (location of sensors)

However, monitoring the same crack, and correlating this information with the traffic passing over the element can show if there is any need to restrict the traffic or make any urgent amendments to the element before the limits are reached (vehicles are calculated by the technologies mentioned in this paper as well).

Furthermore, the proper correlation between the crack and the registered stresses and strains can give an idea of the materials condition and characteristics, *(figure 16)*.

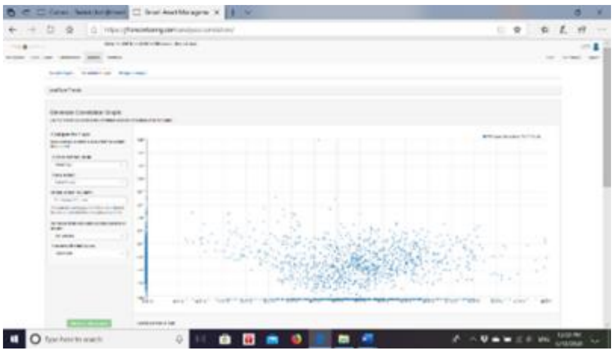

Figure 16. Correlation between parameters in remote bridge sensors

Chemical sensors can provide information about the presence of carbonation and therefore some corroded steel bars which are not well appeared in some of the inspections performed, *(figure 17)*.

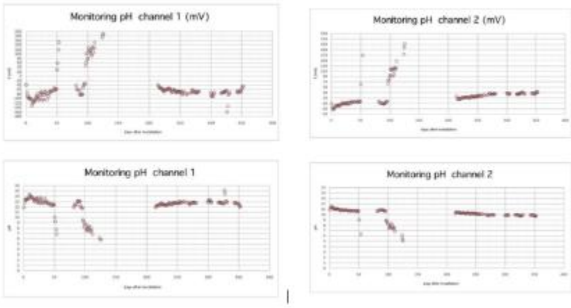

Figure 17. Chemical parameters correlated from bridge sensors

These actions will enhance the rehabilitation project and will make it to be adjusted to the real conditions that need to be corrected, *(figure 18)*

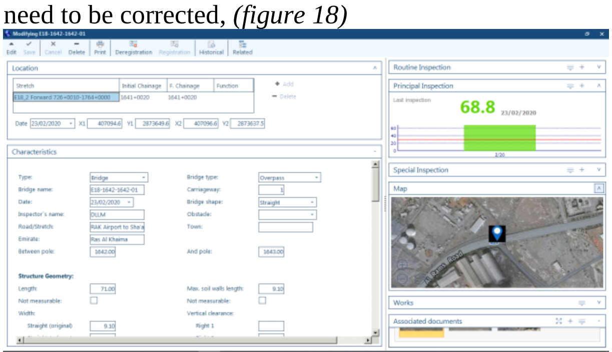

Figure 18. Modification of the Bridge Assessment Condition Index using the information from the remote sensors information

The proper rehabilitation project will be designed according with the traffic supported by the element and (as mentioned in this paper). The best solution will be the one therefore providing the best life cycle solution.

The possibility of having a 3D mesh from LiDAR representing the bridge and the possibility of overlapping pictures with the defects and parameters determining their behavior, allow to model and predict different scenarios as well as create maintenance programs for clusters of similar bridges.

The strategic knowledge of live traffic behavior makes possible to analyze some parameters as the growth factor, which will influence directly, not only the geometry of the roads and the elements within them to be built and maintain, but as well the development of urban or industrial areas, *(figure 19)*.

Figure 19. Road live traffic conditions map

Instant conditions of the traffic are basic to operate the traffic management procedures in the correct way for the road user's safety, using those parameters as well as information of any anomaly in the road that can be attended by the maintenance contractor (accelerating the response time in those events, which can be register in the mobile application), *(figure 20).*

Figure 20. Traffic incidents detection from traffic live monitoring

Knowing the traffic flow and conditions can help to apply restrictions and ban times for some vehicles in a more precise way, *(figure 21).*

Figure 21. Traffic data integration. Parameters analysis

Integration of the traffic database allow to check the efficiency of some operational aspects, as better level of service usually implies a better the operation of the highway.

A good and accurate traffic data will provide better models (in 3D integrating the models created by LiDAR) to predict and model the traffic according to the corresponding economic, social and environmental conditions (see point 2.4).

2.3 Unmanned Aerial Vehicles (Drones) inspection

The inspections performed with drones will help to the creation of 3D models that can be merged into the cloud of points obtained by LiDAR along with photogrammetry technologies with inputs from the images taken during the inspection, (*figure 22).*

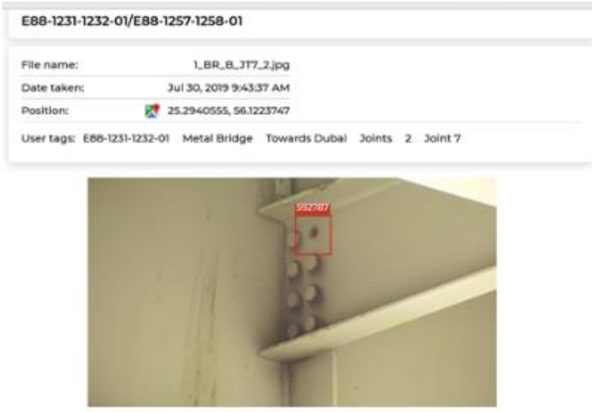

Figure 22. Defects detection from Drone bridge inspection

Damages acquisition by drone can be as well overlapped on the 3D mesh of the bridge and analyze their influence into the context of the element or the bridge.

Information obtained in this inspection can be used as well in traffic modeling programs for example in the case of intersections and junctions. In some of our highways these points constitute "hot spots" and need to be simulated under special conditions. Counting with a 3D model of the bridge will make the microsimulation easier and more realistic, *(figure 23).*

Figure 23. 3D model for traffic simulation implementation

2.4 Mobile application

The mobile application as smart tool allows to manage information of assets in the spot, live, *(figure 24).*

This is an important aspect, considering the synchronization performed between both data bases which representing the reality of the road elements.

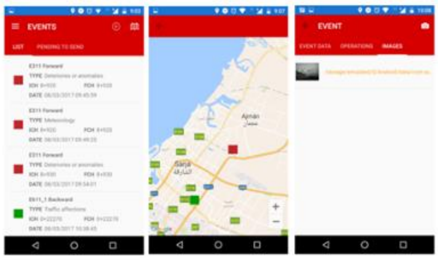

Figure 24. Mobile application for road maintenance incidences

Any new incidence registered by the mobile application will be automatically synchronized with the general database, which allows to manage the assets condition and the traffic management and maintenance actions.

If any incident is urgent an alarm is launched then immediate actions and monitoring with the traffic devices can be performed, *(figure 25).*

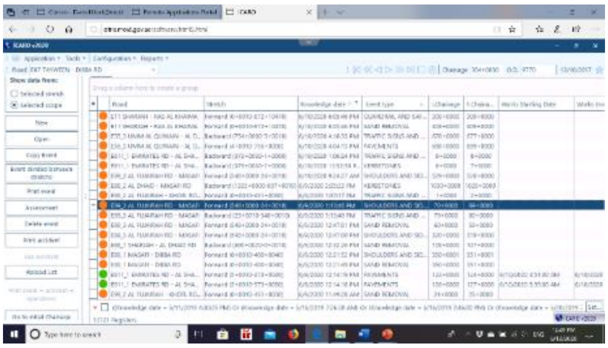

Figure 25. Data base synchronized with the mobile application

Then the MoEI is able to predict the consequences on traffic and road safety meanwhile having any repair or rehabilitation. Discussion with the corresponding police department can be started and all the possibilities to implement the best road safety action according with the urgency of the incidence and the traffic conditions can be done.

A fast update of this inventory data base using the mobile application, will allow as well, to do faster calculations involved in the asset management, maintenance plan and valuation of the assets.

3 Conclusions

The intense work at MoEI during the past 8 years, arose in the creation of a Roads Assets Management that has been continuously developing and improving.

Nowadays, the integration of the tools the MoEI already implemented to do a proper roads management leads to the implementation and integration of the following recent technologies:

- Data collected with LiDAR to create 3d models and cloud of points during the inventory of the road elements
- Remote sensors in bridges to monitor their mechanical and chemical conditions
- Traffic data collection with remote sensors to calculate the traffic parameters
- Drones to perform LiDAR and inspection in bridges to enhance the inspection result in less time and create 3D models for the bridge
- Mobile application to report and register the incidences in the roads live

Continuous feedback of the received information to different specialists in the Ministry allow to increase the service level to the road users and reduce the time response in different situations. All the technologies as mentioned before are interrelated and the outcome can benefit different aspects of the road management.

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