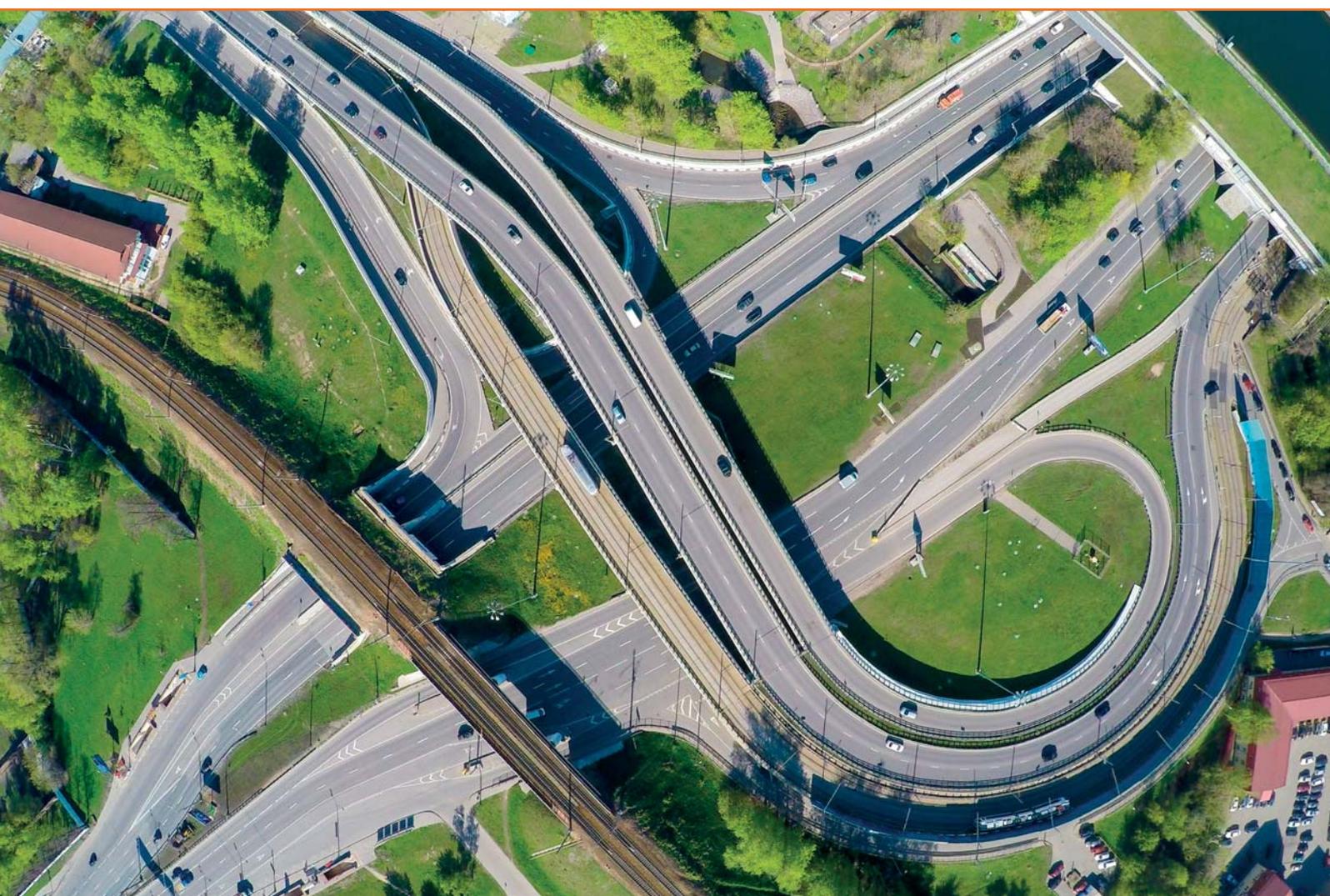


January 2017

Clarity from above: transport infrastructure

The commercial applications of drone
technology in the road and rail sectors



www.dronepoweredolutions.com

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1. Introduction

In May 2016, PwC's Drone Powered Solutions team released our first global report, *Clarity from above*, on the universe of commercial applications of drone technology. The purpose of the report was to present emerging commercial applications of drone technologies, a global overview of regulatory frameworks and the estimated addressable market value of global drone powered business operations across key industries. This was the first attempt to evaluate the maximum market value that drones can capture in those particular industries. According to *Clarity from above*, the total addressable market value of drone powered business operations is over \$127 bn. Industries with the best prospects for drone applications are: infrastructure (\$45.2 bn), agriculture (\$32.4 bn), and transport (\$13 bn). Other industries described in the report were: security, media & entertainment, insurance, telecommunications and mining.

Several infrastructure sectors can benefit from drone technology more and faster than others – especially roads and railways. This report will focus on actual and future applications of drone powered solutions in these two sectors.

Within these two, companies operate extensive networks of complex infrastructure distributed over vast areas, generating high costs of investment monitoring, asset inventory, and maintenance. Today, thanks to technology developments, we have new methods of performing these important activities. Companies actively looking for new ways to accomplish these tasks should look at drone-powered solutions, which can be faster, more cost-effective, and safer than traditional methods. By acquiring various sets of data, drones are becoming essential equipment on construction sites and during regular maintenance and asset inventory activities.

Drones are expected to be a major disruptor in the transport infrastructure industry in the coming years. Early and effective application of this technology can give one a significant edge in this competitive market. Therefore, drones equipped with smart software will have a major impact on the effectiveness of transport network operators.

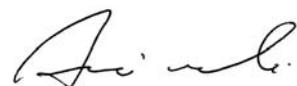
We hope you'll enjoy reading *Clarity from above: transport infrastructure*.



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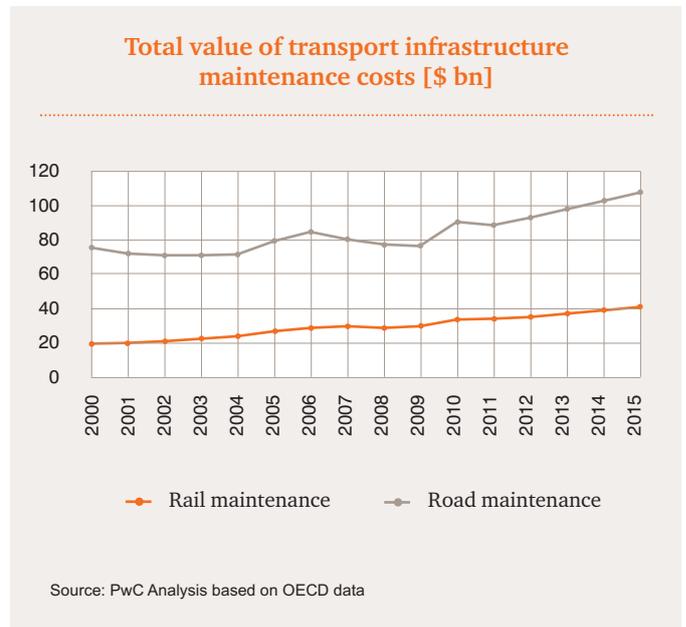
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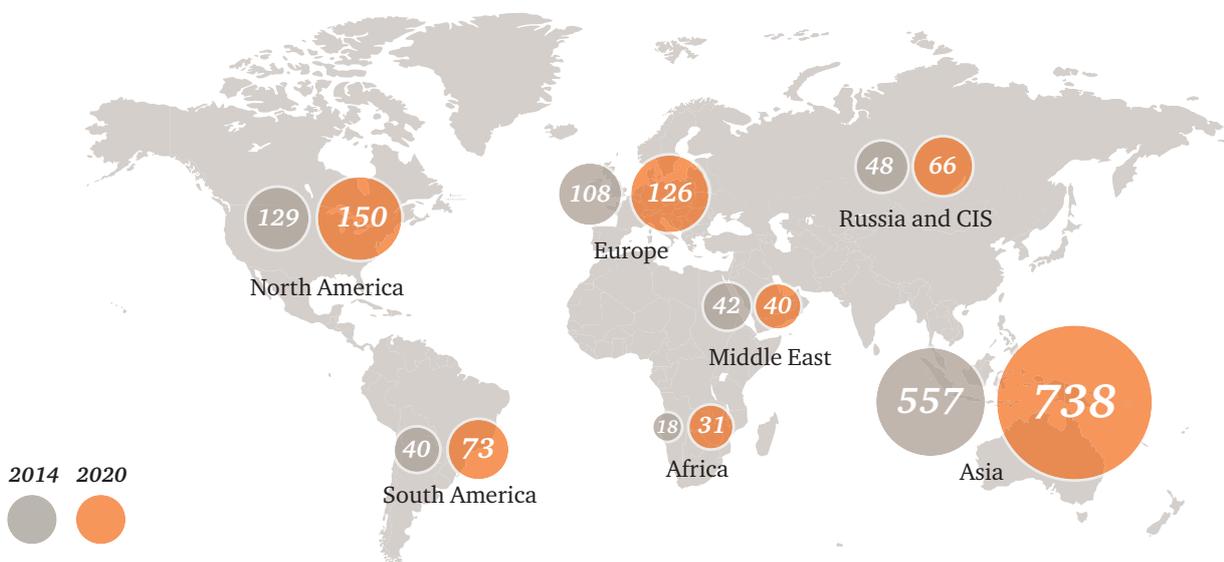
2. Market trends

Transport infrastructure is the lifeblood of any modern society. Constant population growth, increasing affordability of transport, and rising mobility are just some of the reasons why infrastructure needs are growing. Infrastructure operators' investment activity is following the trend, resulting in global growth in capital expenditures of 4.5% annually between now and 2020 (30% total). This will also be reflected in a growth in maintenance spending, since there will be a major amount of infrastructure to keep in operation.

Growth of capital expenditures on transport infrastructure is a global trend. The regions with the highest forecast increases are Africa and Latin America, where investments in transport infrastructure will double by 2020. However, with an increase of capital expenditures of almost \$200 bn, Asia is going to contribute by spending 63 percent of every extra dollar globally spent on transport infrastructure investments. Developed regions such as Western Europe and the US are forecasted to increase their spending by an average of 15% through 2020.



Transportation infrastructure capital investments by region [\$ bn]



This view reflects the current 2016 outlook for infrastructure spending based on Oxford Economics' latest forecasts. All data are stated in \$ bn, using constant 2014 exchange rates.

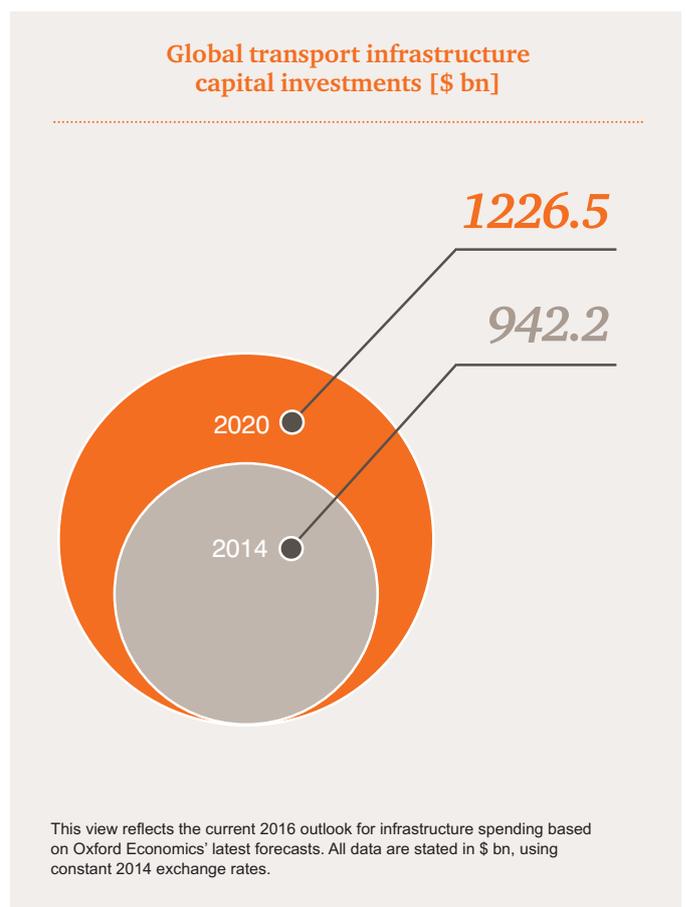
Maintenance is another area that pushes up operating costs for road and railroad operators. From 2000 to 2012, spending on road infrastructure maintenance grew by 20% in OECD countries, while rail maintenance expenditure increased by 80%. This may be partly due to the global increase of investment in high-speed railways.

There are signs that the current trend, in which Asia Pacific is the sole growth driver of infrastructure investment, is going to change over the longer-term perspective. The stabilising political and economic environment in most of Africa, as well as its rapidly increasing population, might lead to an increase of transport infrastructure investments. This region is the least developed in terms of road and rail networks, and therefore requires immense investments to build its capacity for sustainable economic growth. Meanwhile, there are indicators that some of the major Asia Pacific economies, such as China and Indonesia, are overheating, and their current pace of growth is unsustainable.

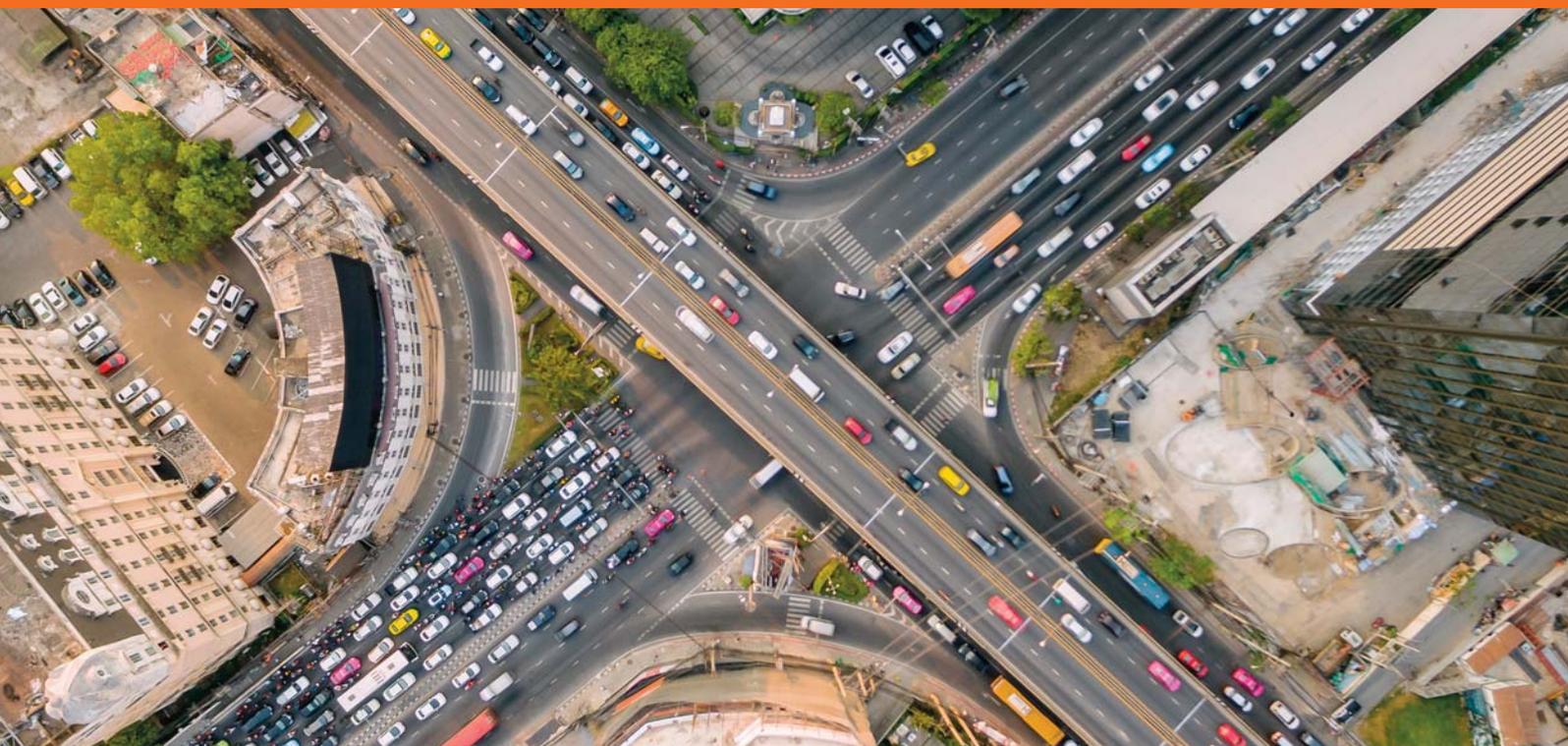
In these circumstances, the next step for industry leaders should be to invest in cost-effective solutions to increase margins and prepare for upcoming disruptions. The extent to which road and rail operators apply innovative technologies on construction sites is also a significant factor that determines performance in a fast-changing environment. One of the most reliable ways for companies to sustain profitability in the long run is to keep capital investments within budget and on schedule, while maintaining the highest quality and decreasing maintenance costs. Drone solutions can be a game-changer in these areas, providing sustainable, low cost and impartial supervision over investment sites, as well as fully operational infrastructure. As these trends continue, PwC anticipates that drone-powered solutions will take on an important role in the road and rail infrastructure sector.

| Railway | Total length [km] |
|--------------------|-------------------|
| North America | 280 349 |
| South America | 102 460 |
| Europe | 158 694 |
| Russia and CIS | 208 117 |
| Asia | 203 330 |
| Middle East | 26 091 |
| Africa | 75 676 |
| World Total | 1 054 717 |

Source: PwC Analysis based on the 2014 World Bank infrastructure data



3. Drone applications for transport infrastructure



According to PwC's Global CEO Survey, technological advances are expected to be a major source of disruption for various industries over the next five years. Technological advances are ranked as more important than shifts in global economic power or demographic changes. Commercial drone applications are among the key developments, and the transport infrastructure sector is no exception. Drones and the data they provide are a game changer over the entire lifecycle of a transport infrastructure investment. Provision of real-time, accurate and comparable 3D modelling data is crucial during the pre-construction, construction, and operational phases of an investment project, and all of this data can be acquired by intelligent and cost-effective drone powered solutions.

3.1 Drones in investment monitoring

Investment monitoring and supervision is one of the major challenges for every road and railroad operator. As new projects are highly cost-intensive, proper execution is a major factor determining the success of an investment, as well as enhancing an investor's competitiveness. Drones, along with advanced 3D modelling software, can be applied effectively at every stage of this process.

\$9bn *Total addressable value of drone powered solutions in investment monitoring*

The fast and accurate data acquisition that drones provide, along with advanced 3D modelling tools, are invaluable during the planning process. They not only facilitate design processes by provision of precise geospatial data, but also help to limit the costs of adjusting plans and designs.

Another key difficulty during the pre-construction phase for both investors and potential contractors is accurate contract valuation. For contractors, precise cost estimation ensures sustainable profit margins, while decreasing the level of risk associated with uncertainty. Conversely, better knowledge about the planned construction area makes it easier for infrastructure investors to carry out both engineering planning and capital budgeting. Additionally, reducing the size of the contingency margin that needs to be set aside can significantly reduce a project's overall capital expenditure.

There are numerous applications of drone solutions during the construction phase. Transport infrastructure construction projects are both highly cost and labour-intensive, and need a high level of supervision to keep the project on track and within budget, as well as addressing other factors such as site safety. The accuracy, simplicity, and cost effectiveness of drones help to address all of those issues. The most important application of this level of supervision is the monitoring of work progress and quality, along with the comparison of materials allocation against project design and schedule. According to the PwC Drone Powered Solutions team's experience from realized projects, construction sites have been surveyed up to **20 times** faster by drones than ground-based land surveying teams.



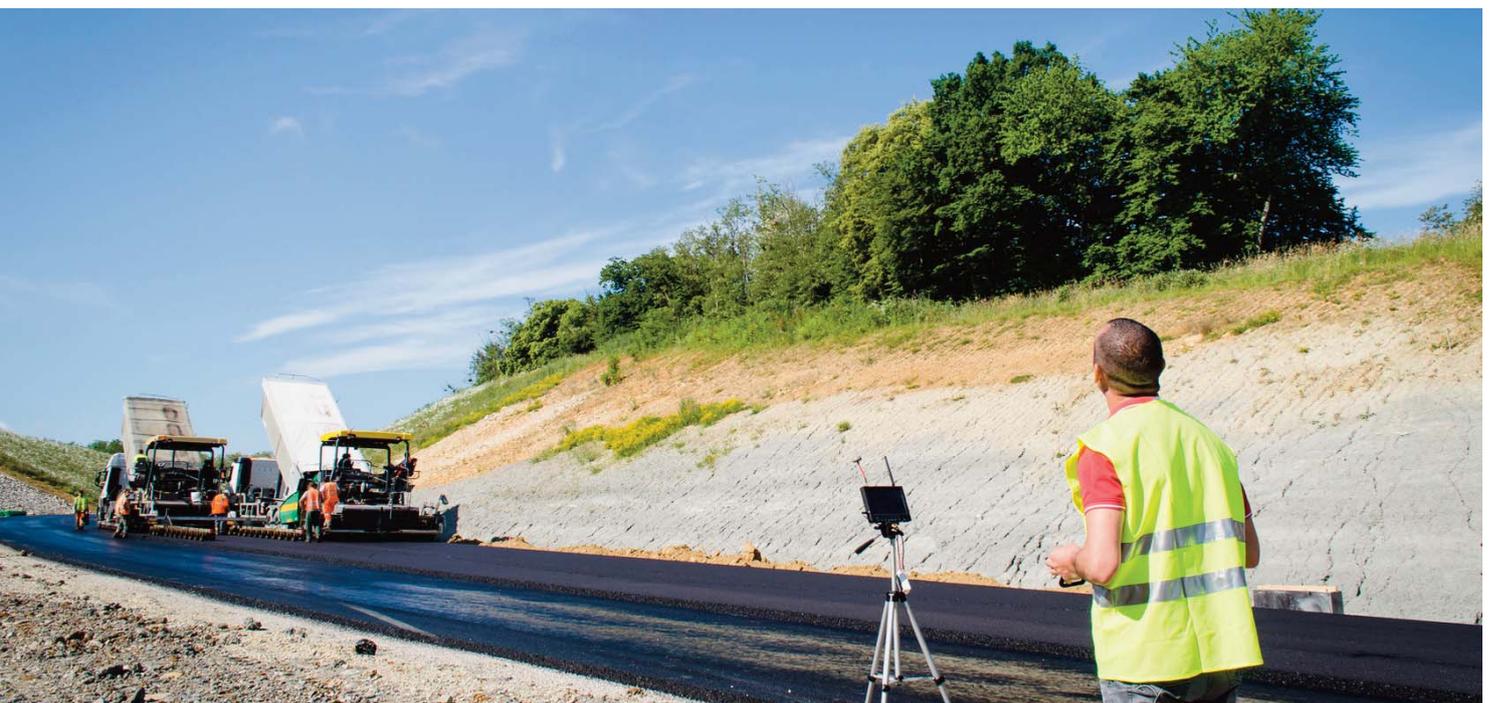
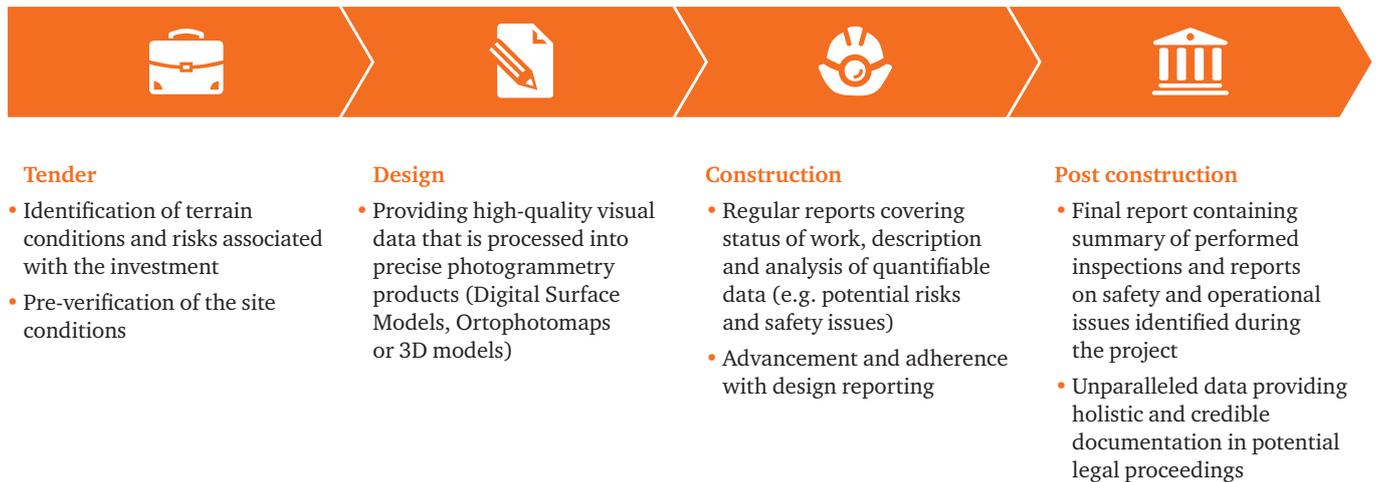
Road construction project monitoring using PwC Geospatial.App

Other applications range from detection and prevention of trespassing, to placement of trench protection, to enhancing site safety. PwC Drone Powered Solutions has calculated that the number of life threatening accidents on an average construction site monitored by drones has been decreased by **91%**. Such knowledge facilitates fast reactions to any deviations from the plan, and in extreme cases, might be used as evidence in litigation. For instance, in only one of the construction project supervised by PwC Drone Powered Solutions, the investor had savings

of approximately \$2.94 million in claims settlement litigation thanks to unparalleled evidence.

During the pre-commissioning phase, drones can be used to precisely assess the effect of work performed in relation to the initial design, and to detect any potential deviations. Additionally, drone solutions can be used to assess a project's impact on both the environment and other parties. Data acquired during the pre-construction and construction phases can also be crucial during later maintenance.

Delivering value at every stage of the capital project



3.2 Drones in maintenance

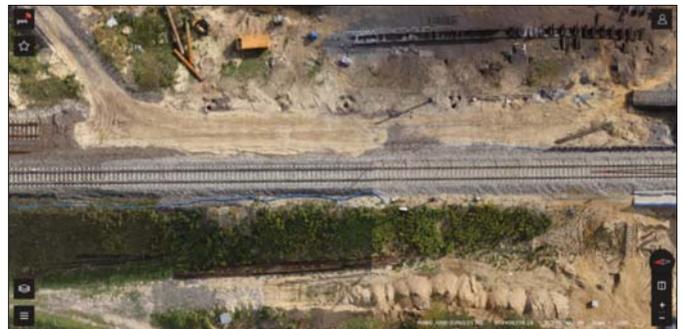
Transport infrastructure such as roads and railroads is the circulatory system of any modern society. The trend of ever-growing mobility is causing billions of people to spend dozens of hours commuting each week. Metropolitan transport networks, as well as long-distance connections, are becoming increasingly crowded. Therefore, sustaining the full capacity of existing infrastructure has become crucial.

\$4bn *Total addressable value of drone powered solutions in transport infrastructure maintenance*

The first applications of drones in infrastructure maintenance were for high-voltage electricity pylons, wind turbines, telecommunication masts, and bridges – structures where frequent and precise monitoring is crucial to ensure safety and correct operation. Drones equipped with high-resolution cameras and scanners can replace humans in conducting precise inspections. Advances in image processing offer precision that is unattainable by the human eye. This is most important when access to infrastructure is difficult or dangerous. Drones can also provide an additional level of inspection: for example, powerline corrosion, wrong connections, or load imbalances all result in overheating, which can be easily spotted by a drone with an infrared camera. This level of information can be achieved without any risk to humans and at low cost. Additionally, data presented in the form of a heat map is easy to interpret and helps to precisely plan repairs. Drones can easily be equipped with other sensors, to provide road and railroad operators with a level of insight that today is very costly, if not impossible.

Regular monitoring is a vital part of all maintenance processes, and transport infrastructure is no exception. Drones can improve the process in various ways. Regular drone inspections provide far more precise information about any kind of problem, mainly thanks to the ease of comparing data points over time, allowing measurement of wear, and forecasts for future deterioration. As automation increases, it is possible that, in the near future, such operations will be performed autonomously. Long-range, fixed-wing, autonomous drones will be able to cover hundreds of kilometres of roads and railways, and provide very accurate data at a very low cost.

Drone-powered innovation in infrastructure monitoring is a game-changer from several points of view. The costs are significantly lower than those of conventional methods, and the information they provide is detailed, comparable over time, and highly applicable in the maintenance planning process.



Rail maintenance and upgrade project monitoring using PwC Geospatial.App

3.3 Drones in asset inventory

One of the drone applications that has been gaining interest in the transport industry is stocktaking and cataloguing. Maintaining control over hundreds or thousands of individual elements is significantly time-consuming and labour-intensive. One of the effective examples of drone powered automation is car monitoring and stocktaking within a railyard. Autonomous drones operate within a pre-defined area, equipped with scanners to identify particular cars, and cameras with a real-time flight control system that prevents collisions. This solution is being developed to autonomously detect damage to cars, significantly speeding up the inspection and stocktaking processes, and cutting the costs of operating and managing a rail fleet.

Stocktaking can be conducted in parallel to the maintenance monitoring process. For road and railroad operators, monitoring and cataloguing elements in the direct vicinity of their infrastructure, such as signs or transformers, is a time-consuming and labour-intensive process. This can also be automated by drones. When equipped with LoRa transceivers, barcodes, radio frequency tags, or other identifying labels, such elements can be approached and scanned by a drone, and the information compared to a catalogue of data to identify changes.



Road bridge maintenance and asset management using PwC Geospatial.App

4. Future drone applications for transport infrastructure



There is a wide range of new technologies that road and railroad operators can use with drones to enhance investment monitoring and maintenance. One of the most interesting examples is implementation of machine learning into drone operations. Today, most data processing & analysis work has to be done by humans. However, we can improve that process by teaching machines to do those tasks autonomously.

4.1 Building Information Modelling

Standardized implementation of drone technology integrated with the Building Information Modelling (BIM) methodology into the capital projects process will significantly improve not only the construction process itself, but also post-construction operation and maintenance of the infrastructure. Enhancing trust and information-based cooperation between all stakeholders is crucial at every stage of the capital project. For this very reason, integration of drone technology and BIM has the potential to be disruptive and transformative to the operational models of companies within the whole infrastructure lifecycle value chain. Cyclical and fast provision of high quality geospatial data by a drone from a construction site delivers a new level of engineering-grade information regarding capital projects. Such information is central to the very idea of the Building Information Modelling methodology and, therefore, can be successfully integrated with BIM models and utilized in design, construction, commissioning, operations, and maintenance processes.

4.2 Machine learning

Machine learning software uses an algorithm that learns how to solve complex tasks by utilising a form of training, similar to the way the human brain operates. By applying deep learning to drone solutions, we can decrease the time and cost necessary to process, integrate and analyse data gathered during inspections. Automation of drone operations – not only data analysis, but also drone flights – is happening right now thanks to manufacturers making drones capable of autonomous flights. In the very near future, we will see drones flying autonomously to preselected points, to collect data on infrastructure, which highly sophisticated software based on learning algorithms will analyse, informing human operators about damage or suspicious activity.

4.3 Augmented and virtual reality

The next technology offering synergies with drones is augmented reality, which, today, is starting to be used to improve access to essential information on construction sites. Visualising data, such as building plans, on mobile devices or helmets helps construction teams in the field understand how various systems and components fit together during construction. Augmented reality can place a model of the structure directly into the view of a site in real time, allowing workers to see the exact location, assembly instructions, materials information, warnings, and other information associated with a project. This makes the entire construction process easier and faster. By combining data gathered through drones with AR capabilities, workers get access to the most current information about where and when to install the next piece of a structure or repair a broken part. While augmented reality can help construction teams, virtual reality helps designers and architects visualise a structure to see how everything will look. They can make instant changes smoothly, and see the effects immediately without risking delays or serious errors.

4.4 Drones as construction equipment

Investment monitoring and asset inventory are not the only drone application being developed for the infrastructure industry. We can also expect to see drones performing dangerous tasks at great heights for small-scale construction works and repairs. Future drones will move building materials as well as assemble, weld, and attach parts. One great example of the potential of drones in those areas is the Aerial Construction project, completed by a team of scientists from ETH University of Zurich, under the supervision of Professor Raffaello D'Andrea. The aim of the project was to develop methods and techniques for robotic aerial construction. The team from ETH was able to build a bridge out of ropes using an autonomous swarm of drones capable of crossing various types of obstacles. PwC envisions development of similar swarms of autonomous drones to build small-scale objects and internal infrastructure (e.g. ventilation systems). They will perform those tasks faster than humans, while reducing the risk of death and injury. Due to highly advanced sensors and software, they will be able to navigate on their own, as well as transport materials without human help.

5. Opportunities and challenges



5.1 Key opportunities

PwC expects that the adoption of drone powered solutions in the road & railway sectors will be driven by the following three factors.



Financial and legal support

Drones have become a major topic in most discussions about how technological innovation can influence the global economy. The advantages of using drones to perform industrial inspections, especially in the infrastructure sector, are becoming very clear and persuasive for most governments and large enterprises. Therefore, it is not surprising that the most technologically aware and developed countries are already supporting the acceleration of development and implementation of drone technologies across many industries. For example, the US government has allocated \$35 million to accelerate the understanding of how to intelligently and effectively design, control, and apply drones in areas such as monitoring and inspection of physical infrastructure. Similar programs, coupled with strong legal support, are being deployed by the Chinese and Israeli governments to help their companies introduce drones into their daily operating processes faster and more easily.



Enhancing data processing & accessibility

Clients expect that data acquired during industrial inspections will be available immediately, on any type of device. For instance, an investor financing road construction wants to be informed about the pace of work, any type of delays, and any accidents on site as soon as they happen. The shorter time required to process data and enable access to information will be another factor boosting the implementation of drone technologies by companies from the road & railway industries.



Rapid technology development

While a reduction in purchase prices and operating costs has contributed to a surge in mainstream UAV usage, further appeal has also been generated by advances in technology, which have improved UAVs' capability and usability, dramatically increasing the potential application of drones. Further expected development in battery capacity, construction materials and software, especially regarding building information modelling and drone integration, will definitely increase UAVs' usability for industrial inspections.

5.2 Key challenges

Integrating drone powered solutions into the operational processes of infrastructure companies will face several challenges.



Aviation risk

National aviation authorities, together with private companies, have to develop a complex air traffic management system for drones to prevent collisions with other aircraft. Such systems have to allow drones to see and avoid other aerial vehicles and potential obstacles, as well as communicate with air traffic controllers. In addition, the systems have to be integrated with air traffic management systems for manned aviation from other countries to guarantee an undisturbed, fast flow of information.



Privacy

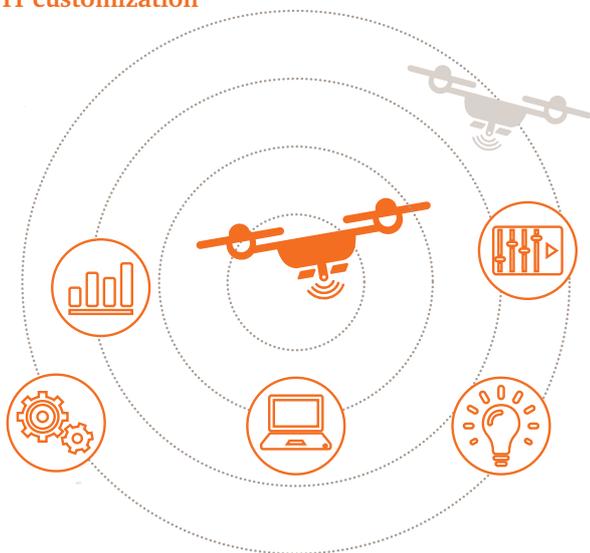
Privacy is one of the main concerns expressed in the context of drones. Drone operators perform flights over various types of sites, collecting a vast amount of data, sometimes including confidential or sensitive information about private property or behaviour. There are no clear rules, or even guidelines, on how companies should store the data, what types of data should not be collected, or how individuals and companies can defend their privacy rights. The uncertainty regarding possible use of data gathered by drones may discourage companies from implementing drone-powered solutions.



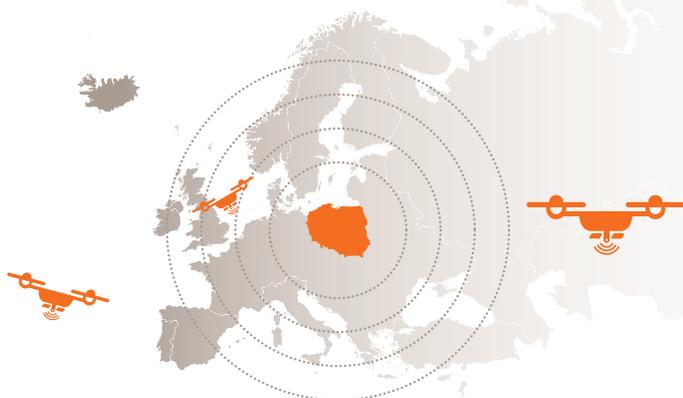
6. Drone powered solutions

Wide scope of competencies:

- visual data processing and analytics
- process transformation
- IT customization



Drone Powered Solution (DPS) – the world’s first professional services consulting team dedicated to industrial and business applications of drone technology



Drone Powered Solutions (DPS) is a global centre of excellence located in Europe. The team helps clients from various industries to maximize the potential offered by drone technologies.

Established in Poland in early 2015, it is the world’s first professional services consulting team dedicated to industrial and business applications of drone technology, and its location in Poland is no accident: Poland is one of the first countries worldwide to have adopted detailed laws regulating the industrial use of drones (as early as 2013).

Over time, DPS has worked with clients from various industries on testing applications of drone technology in their operations. Drone technology proves to be a powerful tool for many sectors of the economy. We believe that skillfully making use of the possibilities offered by this technology will greatly improve the quality of daily processes, combining high precision, simplicity and unmatched cost-effectiveness.

Thanks to PwC’s rich experience in strategic and operational planning and implementation, DPS support will not only help companies select the appropriate hardware, but also implement complete and comprehensive operational systems. The scope of our competencies includes strategy, process transformation, IT customization, visual data processing, and analytics. These competencies enable DPS to deliver end-to-end services to clients. DPS has also developed its own proprietary delivery software, PwC Geospatial.App, allowing for integration, presentation and management of comprehensive data sets. Thanks to its wide spectrum of functionalities, the tool enables easy and instant decision-making.

The DPS team already has unique experience, proprietary solutions, and methodologies, but we are not stopping there. We are constantly focused on developing new ideas and technology (e.g. machine learning) to efficiently support customers in the new drone reality.

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