

Precision forestry: A revolution in the woods

Advanced technologies could improve forest management significantly. What areas are most promising, and how can forestry companies start their digital transformation?

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Digital technology is revolutionizing industries around the globe, from manufacturing to healthcare. Even agriculture is undergoing enormous change due to technologies like variable-rate fertilization and automated harvesting. Forestry, on the other hand, has lagged behind most other industries in the adoption of digital technology. This, however, is finally starting to change. Studies are already showing productivity increases in general agriculture at rates of 5 to 25 percent annually, with returns on investment of one to two years for digital technology (depending of course on many factors, such as farm size, crop selection, and other conditions). Analogous gains are not merely on the horizon for forest products but are also being realized by some pioneers today. The size of these gains is comparable only to the shift from animal-powered to mechanized processes and, in food farming, the Green Revolution of the 1960s.

That said, in forestry-management science, digital solutions currently confront a system that still operates largely on the basis of fundamentals developed by Hans Carl von Carlowitz more than 300 years ago.¹ Processes are highly manual and analog, with “broad-brush” management prescriptions. Introducing advanced technology in forest management faces several challenges:

- There is **little corporate involvement** in forestry; 76 percent of forests globally are publicly owned,² and most of the remainder are held by small private owners (who typically hold, on average, less than one hectare, or roughly two-and-a-half acres).
- State and other public forest owners tend to be relatively conservative in their management style and, to a greater extent than private enterprise, **need to balance diverse objectives** for commercial performance with social and environmental goals.
- Many private forest owners have operations characterized by a **lack of scale and expertise** required to adopt the latest technologies.

- Large-scale commercial forests, from eucalyptus plantations in South America to managed natural forests in Europe and North America, are in **remote and rugged terrain**, presenting many challenges for adoption of new technologies.
- While a wide range of precision forestry technologies exists, **relatively few practical examples** are up and running, and few understand how the technologies translate into real use cases.

However, inspired by advances in agriculture, forestry operators globally have begun pioneering the use of advanced technologies to improve forest-management results. Within the industry, this approach is widely called “precision forestry.” The natural first movers are those plantation forestry operators who have a long track record of innovation and continuous improvement focused on productivity. This management style is closest to agriculture, with monocultures, selectively bred tree species, and a relatively high degree of automation—indeed, these forests are often referred to as tree farms.

But it is not only in plantation forestry regions, such as South America, South Africa, and Australasia, that we see a push toward precision forestry. In Scandinavia and North America, forestry companies are also awakening to the need for increased sophistication in their management systems. For one thing, their customers and other industries they interact with (such as pulp and paper or transportation) are becoming increasingly advanced; for another, most forestry companies see an integrated digital approach as a source of competitive advantage.

The advantages are various. Advanced technology can enable lower delivered costs for wood. It also makes possible higher wood yields from a given area of forest, which is especially valuable in Western Europe and East Asia, regions where little additional forest land is available. For institutional forest

owners, such as pension funds, success in precision forestry is seen as a license to expand investments to new regions outside of North America.

The potential for value creation from improved forest management is significant. Besides the ecological benefits of increased productivity, which relieves pressure on natural forests, there is substantial economic and social value at stake. Globally, about 300 million hectares of plantation forests, an area roughly the size of India, and 900 million hectares of natural forests used for wood production, an area slightly smaller than the size of China or the United States, together supply nearly two billion cubic meters of industrial wood (for example, for construction, paper, and packaging) and two billion cubic meters of fuelwood for household heating and cooking. The

economic value of the industrial wood is on the order of \$200 billion, while the fuelwood remains a critical source of energy for households in developing countries.

Precision forestry pioneers

Precision forestry is enabled by wide range of emerging technologies, such as drones or unmanned aerial vehicles (UAVs), laser scanning (lidar), and soil sensors, supplied by a growing flora of specialist vendors.


But precision forestry is not simply the adoption of digital technologies. For forest managers, it involves a paradigm shift, from a highly manual and analog system with broad-brush management prescriptions to a system with digital data capture and planning, granular management prescriptions, and tight operational control (Exhibit 1).

Exhibit 1 The building blocks of moving from traditional to precision forestry require a new approach.

From:

Traditional forestry systems involving highly manual and analog processes, “broad-brush” management prescriptions



-  Natural regeneration of forests with seed trees of same genetic material
-  Use of 2–3 standard fertilization prescriptions depending on broad soil-type classifications
-  Manual in-field forest inventory based on sampling to inform production planning
-  Motor-manual harvesting with no data capture
-  Reacting to forest fires detected only by direct observation

To:



-  Selectively bred and cloned seedlings, raised in nurseries under tightly controlled conditions
-  Site-specific fertilization treatment based on granular assessment of soil nutrient deficiencies
-  Digital forest inventory using drones and light detection and ranging (lidar), or in-forest scanning with smartphones
-  Fully mechanized harvesting, integrated with supply-chain planning
-  Satellites and drones to provide early fire detection and inform centrally planned response

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Each of the precision forestry technologies offers improvements to forest management through one or a combination of four ways:

- tighter control of operations with improved data collection
- increased selectivity of prescriptions to match site and needs, for instance, soil nutrients and the genetic material of seedlings planted
- automation of operations, from nurseries to wood logistics
- optimized decision making with advanced analytics

To illustrate the potential already being realized, one tangible and spreading example in mechanized harvesting is the cut-to-length (CTL) system, which overcomes several drawbacks of conventional logging. Traditionally, tree felling and log manufacture are carried out by an operator with a chain saw; tree trunks (“stems”) are extracted with wheeled skidders or cable systems to roadside and then sawn into logs. Trunks are connected to cable systems manually by operators, climbing over piles of debris and wary of runaway trunks—a dangerous job called “breaking out.” Ad hoc decisions on what log grades to make from each tree trunk are made mentally by chainsaw operators, guided by a few basic log specifications and prices.

The new CTL technology, which has evolved in Scandinavia over the last two decades, is being adopted in many other regions to gain its clear benefits. The system is fully mechanized with a “harvester” vehicle that fells trees and makes logs in one process in the forest, paired with a “forwarder” that moves these logs roadside. The system is also highly digital: cutting instructions are relayed in real time to the harvesters, where onboard computers optimize the mix of log grades made from

each tree, using sensors mounted on the harvester to measure trunk shape and quality. Production data is linked to a GPS and relayed back to the office, together with data on machine productivity, and other performance indicators, such as fuel efficiency.

The greatest advantage of this system is safety, with operators safely located inside protected cabs, far removed from trees and logs (which can weigh up to one metric ton). At most sites, the CTL system also improves labor productivity. And the system gives forest managers much more control and ability to optimize their supply chain, forest value recovery, and planning for the next crop. For example, they can adapt production plans instantly in response to customer orders. Data on grade outturn from a specific site can inform decisions on what tree species to plant for the next crop, what fertilizer regimen to employ, and at what age to best harvest a crop. While the CTL system is now standard in Scandinavia and spreading internationally, it implies a giant leap in the technologies and processes used in many forest regions globally.

Lidar and UAVs are examples of much newer technologies being adopted globally for various applications in forestry. Lidar is a laser-based surveying technology used in many industries and fields of research. Sensors measure the distance between emitted and reflected pulses of laser light, to create a 3-D image (“point cloud”) of the object scanned. The sensors can be mounted on aircraft or ground based. In forestry, they are increasingly used to produce terrain or water-flow models and derive estimates of standing wood inventory (such as trees per hectare, tree heights, and trunk diameters). The potential applications for lidar are many and powerful. For example, more precise knowledge of terrain, water flows, and forest inventory can help optimize road construction, with roads placed to minimize cost and environmental impact and built in the best sequence to match harvest plans. The benefits can be far beyond initial expectations. One

company’s managers commissioned lidar scanning of their forest to get better inventory estimates and found even greater benefits in using the terrain models in their harvest-planning process (deciding how to harvest a unit of forest, including the type of equipment required and its placement).

UAVs are increasingly used in forestry for surveillance and mapping. They can also be fitted with lidar or thermal cameras to collect forest-inventory data, detect outbreaks of pests and diseases, and give early warning of forest fires. There are even early attempts to utilize UAVs in remote or difficult terrain for simple forestry operations, such as planting seeds, spraying for weeds, pests, and diseases, and fertilizing young seedlings. As with lidar, the potential applications for UAVs are many, as they are both tried and tested, and the underlying UAV technology continues to evolve.

Technological landscape: 15 promising practices

The technological landscape of precision forestry is a jungle, with some clear “canopy” practices and dense undergrowth. Technologies are rapidly evolving and being trialed and adopted in a variety of ways. Some, like mechanized harvesting, are well established in parts of the world, and their use is spreading to new geographies. Others are most useful in specific settings (for example, genetic improvement in plantations). Most are based on new technology with many potential applications in all kinds of forestry management globally.

From our work with forestry-management companies in all main forest regions, we have identified 15 precision forestry technologies or practices that show the greatest promise to transform operations and improve forest-management results (Exhibit 2). As outlined below and illustrated with brief examples of impact, these technologies involve activities in all steps of the value chain—from plant genetics and nurseries to

wood delivery to sawmills, pulp mills, and energy plants.

Genetics and nurseries

While genetics are never the whole story, choices about tree genes and early nurture clearly have a major role to play. There are two key practices:

- *Advanced genetic improvement* entails gene mapping and marker-based breed selection to ensure plants have the genetic profile best suited to the site and end use. In one example of how it can help, a plantation forest owner in South America expects to raise yields from its eucalyptus crops by more than 25 percent by 2025. This would be accomplished through selective breeding of trees and use of clones—in a region that already has world-class forest productivity (typical forest rotations of about six years, versus 50-plus years in Europe and North America).
- *Automated nurseries* are fully enclosed and controlled environments for raising seedlings under optimum conditions for plant health and growth. These can have a big effect: one new state-of-the-art nursery in Uruguay, for instance, reduced seedling production time by 15 percent (lowering it to 100 days, from 110 to 120 days) and brought down water consumption by 75 percent.

Forest management (silviculture)

Some definitions of silviculture broadly include all four of the areas discussed here. We find the narrower definition—managing the production and tending of forest stands—useful to group-specific applications of digital technologies to the knowledge of silvics (trees and their habitats). Of course, all the practices share the overall goal of achieving both biological or botanical and economic objectives in forest management.

- *Site-specific management* includes granular prescriptions adapted to specific site needs, such

Exhibit 2

Fifteen promising practices in precision forestry's technological landscape.



Genetics and nurseries

Advanced genetic improvement: gene mapping and marker-based breed selection to ensure plants have genetic profiles suited to the site and end use.



Automated nurseries: fully enclosed and controlled environments for raising seedlings under optimum conditions for plant health and growth.



Forest management (silviculture)

Site-specific management: prescriptions adapted to site needs, eg, fertilization and drainage, often based on data from soil sensors.



Fire monitoring: digital monitoring of fires, with UAVs or satellite, eg, to provide early warnings and coordinate fire-fighting.



Pest and disease monitoring: digital monitoring of potential outbreaks, eg, with UAVs, and coordinated responses to minimize damage to the forest.



Water-management systems: central control of water infrastructure (eg, flood gates) based on weather, soil moisture, canal water levels, and analytics.



Mechanized silviculture: increased use of machinery to improve safety, labor productivity, and operations, eg, via fertilization and weed control.



Harvesting

Digital inventory: measurement of forest standing inventory—volume, species, and sometimes grade mix—by aerial remote sensing and in-forest devices.



Mechanized harvesting: fully mechanized systems to improve safety, productivity, and process control.



Wood delivery

Remote/automatic loading: loading cranes that can be operated remotely (eg, from a truck cab or central office location) and eventually autonomously.



Wood logistics optimization: use of advanced software to control the central dispatch of trucks and other transport infrastructure.



Across the full value chain

Forestry-planning models: software to support forest-management decisions, from strategic to tactical and operational.



E-dashboards: used to visualize performance data, based on one central, standardized, and electronic data repository.



Field support tools: mobile devices deployed in the forest, giving supervisors access to forest information systems and planning tools.



Advanced analytics: analysis of data to solve complex problems, eg, identifying constraints on tree growth at a micro level and determining effective interventions.

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as fertilization and drainage, to improve the cost-effectiveness of interventions, often based on data from soil sensors. For example, research in South Africa shows that soil preparation and fertilization targeted to specific sites can improve forest yield by 10 to 50 percent.

- ***Pest and disease monitoring*** encompasses digital monitoring of potential outbreaks, for instance, with UAVs, and coordinated response management to minimize damage to the forest. Studies show that remote sensing with UAVs can achieve a detection accuracy of 80 to 95 percent for pest and disease outbreaks, over very large areas of forest.
- ***Fire monitoring*** entails the digital monitoring of fires, with UAV or satellite, for example, to provide early warnings and coordinate fire-fighting efforts. In 2017, one of South America's largest plantation forest owners lost 4 percent of its forest area due to fires; to reduce future losses, the owner is now investigating how to improve detection and control systems.
- ***Water-management systems*** involve the central control of water infrastructure (such as flood gates and irrigation) based on weather, soil moisture, canal water levels, and predictive analytics. One plantation forest operator in Asia reduced the risk of flood damage in its forests by 70 percent by implementing a water-management system. The system uses an analytical approach that includes division of land into water zones and analysis of water run-off for each water zone to determine the infrastructure required to avoid flooding and maintain an optimal water level in canals.
- ***Mechanized silviculture*** relies on the increased use of machinery, where appropriate, to improve safety, labor productivity, and effectiveness of operations, through fertilization and weed control, for example.

Globally, less than 15 percent of forest establishment operations are fully mechanized, yet, with mechanization, the total cost of some treatments is up to 20 percent lower.

Harvesting

The use of digital technologies for inventory and harvesting is bringing substantial gains, allowing for greater yields and grade outturn, as well as improved efficiency and less waste during harvest.

- ***Digital inventory*** offers measurement of forest standing inventory—volume, species, and sometimes grade mix—by aerial remote sensing (for example, lidar) and in-forest devices (for example, smartphones). To illustrate its power: in working with an operator whose inventory consisted mostly of stands that were too old (more than 60 percent) and whose volume estimates had a standard error of around 40 percent, we found that implementing digital inventory reduced the standard error to less than 10 percent and significantly sped up the task of inventorying.
- ***Mechanized harvesting*** involves fully mechanized systems to improve safety, productivity, and process control. For instance, since the 1990s, the Swedish industry as a whole has doubled labor productivity of forestry operations, largely through mechanized harvesting (a CTL system), driven by safety concerns and high labor costs. And there is still potential to improve even further. Research suggests, for example, that 3 to 4 percent of sawlogs (the most valuable part of the tree) are unnecessarily downgraded to pulplogs due to imprecise measurement of logs by harvesting machine sensors.

Wood delivery

In wood delivery, new solutions also contribute significantly to improving key performance indicators such as safety levels and waste reduction.

- *Remote/automatic loading* includes loading cranes that can be operated remotely (for example, from a truck cab or central office location) and eventually autonomously. Such solutions eliminate the risk of injury from falling logs completely in the case of office-based loading; the truck-cab solutions include specially reinforced cab roofs and frames.
- *Wood logistics optimization* involves the use of advanced software to control the central dispatch of trucks and other transport infrastructure. A pulp and paper company in the US reduced the total delivered cost of wood to their mills by 2.5 percent by implementing a tool to optimize wood logistics. Likewise, two Swedish companies used a similar tool to identify a 5 percent reduction in transport costs to their mills, through wood swaps between the companies to optimize their combined supply chain.
- *E-dashboards* visualize performance data, based on one central, standardized, and electronic data repository. An Asian plantation forestry company reduced its backlog of silviculture operations from more than 1,000 hectares to less than 100 hectares through increased transparency on the status of every compartment.
- *Forestry-planning models* are software to support forest-management decisions, from strategic (for example, long-range supply plans) to tactical (for example, road construction) and operational (for instance, harvest scheduling). A Brazilian plantation forestry company improved forest productivity by 5 to 10 percent by using planning software to optimize the alignment of nursery production with planting and harvesting activities.
- *Advanced analytics* involve the analysis of large amounts of data to solve complex problems, for instance, identifying critical constraints on tree growth at a micro level and determining the most cost-effective interventions (such as using fertilizer to improve soil nutrition). Advanced analytics are still relatively untested in forestry but have proved their potential in downstream (for instance, reducing pulp-manufacturing costs by 5 to 6 percent), and they are expected to realize high improvements in optimizing site-specific treatments for faster tree growth.

Across the full value chain

As in other industries, some of the highest-potential applications of the new technologies and practices are those that span the full value chain.

- *Field support tools* are mobile electronic devices deployed in the forest, giving supervisors constant access to forest information systems and planning tools. Such tools made a difference for one company in South America, which recently introduced handheld electronic devices linked with forest information systems, contractor management systems, and planning tools for harvest and log transport. This resulted in a 10 percent reduction in supervisor administrative work (such as entering log-stock data), a 10 to 20 percent reduction in wood waste due to quicker escalation of issues with contractor performance, and a 15 to 20 percent reduction in discrepancies of stock-level data.

All these technologies have proven potential to significantly improve forest-management results, including higher forest productivity, lower operational costs, and improved planning effectiveness. While the quickest gains can typically be made through better planning and cost reduction, the largest potential driver of long-term value creation is through improved tree growth. And in some regions, with very short forest rotations, these gains can even be achieved within five to ten years.

Implementing a precision forestry program

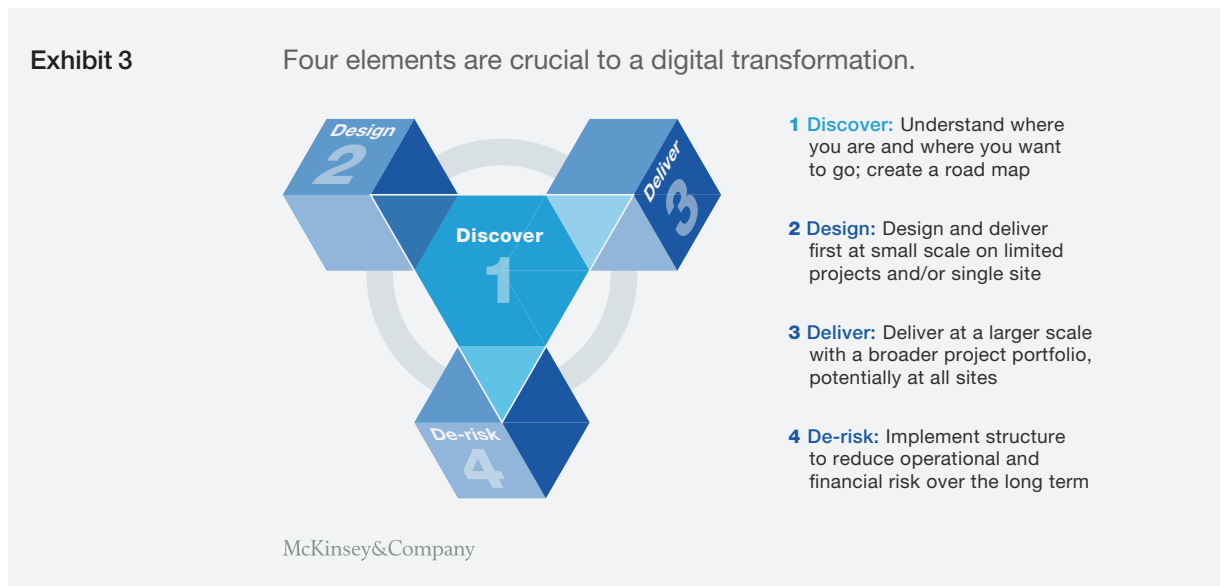
Many leading forestry companies globally are adopting precision forestry technologies, and there has been a noticeable proliferation of technology suppliers seeking to develop this space. While many precision forestry technologies remain in trial phases, some are already established and increasingly gaining traction. The availability of these technologies, even of those being trialed, signals a major shift in the industry.

Most forestry companies will find great potential for value-producing transformation. This applies across diverse geographies and types of forestry operations, from plantations in tropical regions to managed natural forests in North America and Europe. The key to capturing that value will be a holistic digital transformation that brings together the disparate applications of new technologies.

Typically, we describe the way we would structure an end-to-end digital transformation in terms of the four Ds: discover, design, deliver, and de-risk (Exhibit 3).

From the outset, it is critical that senior executives align on their vision of digital as a key priority for future growth in a competitive market. As they diagnose the digital state of their organization and take the first steps in translating that vision around a prioritized road map, it should become increasingly clear how they can use digital to unlock and sustain new competitive advantages. Realizing this vision—moving from the ad hoc and piecemeal use of new technologies to being poised to drive the future of forestry—requires a digital transformation.

To fully capture the value of digital, we emphasize a Digital & Analytics Transformation Approach



While many precision forestry technologies remain in trial phases, some are already established and increasingly gaining traction.

(DATA). Our DATA methodology builds on a lean transformation by adding digital components and analytics to ensure sustainable step-change performance improvement. This is accomplished by leveraging state-of-the-art digital and analytics tools and methods with a dedicated team. The team drives the transformation through capability building hand in hand with optimizing all core processes in agile-at-scale sprints (lasting two to three months). Finally, to ensure alignment with the digital vision, a flexible, platform-based software solution is required both to start deployment immediately and to ensure resiliency and efficiency as new technologies are trialed and take off.

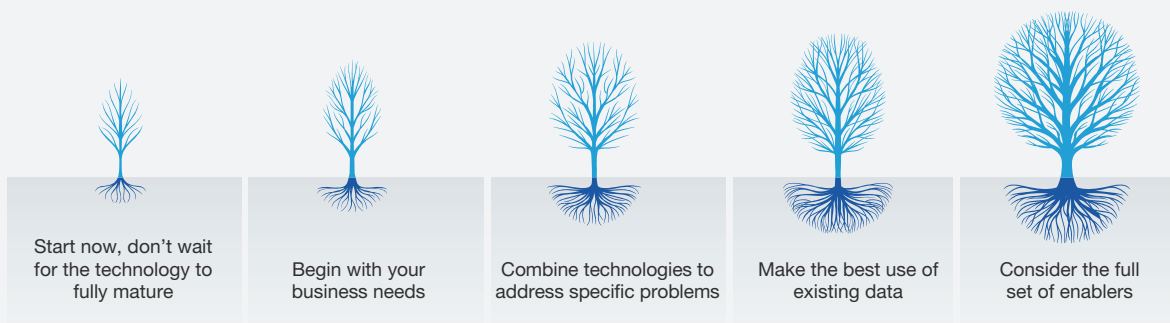
From our experience to date, we can offer five practical pointers to ensure that a company is well aligned at the start of its precision forestry digital transformation (Exhibit 4):

- **Start now, don't wait for the technology to fully mature.** For instance, use manual reading of UAV images while algorithms are being built, because this helps narrow down the exact problems to solve, and the requirements for doing so.

- **Begin with your business needs.** Many precision forestry technologies are used for data collection, which is only the starting point and should be followed by analytics, and only then decision making.
- **Combine technologies to address specific problems.** The new technologies are most powerful when used in combination, for instance, for forest re-establishment: UAVs to collect stocking data, analysis to identify low stocking hot spots, and decision making to prioritize areas to replant.
- **Make the best of use of existing data.** This, if cleaned and integrated into one unified data set, may be enough in itself to run predictive analytics and drive improved decision making.
- **Consider the full set of enablers.** Don't look at just the new technologies—consider the IT backbone, business processes, capabilities, and organizational setup as well.

With these points in mind, we see early evidence that precision forestry can drive significant and lasting

Exhibit 4 Five steps in a digital and analytics transformation approach for forests.



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improvements in forestry organizations. While the technology is relatively new, it has exciting potential to reinvigorate and even revolutionize forestry management at all levels.



Just as Hans Carl von Carlowitz wrote in 1713, today's forest managers understand that regeneration—ensuring the “continuously enduring and sustainable use” of forests as an essential natural resource—is not a constant, where iron-clad principles or practices can be applied by rote. For such assets to flourish, their management needs to be dynamic. Today, that means guided by the superior real-time insights attainable with digital and related technologies for precision forestry. The advent of these new tools and capabilities offers potential beyond raising the efficiency of practices handed down from the 18th

century. It heralds the start of a revolution in how we manage the health and the performance of the world's forests. ■

¹ *Sylvicultura Oeconomica*, written by Hans Carl von Carlowitz in 1713, is considered by many the first book on sustainable forest management.

² *Global Forest Resources Assessment 2015*, Food and Agriculture Organization of the United Nations, fao.org.

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