PREPARED FOR

AEM

Association of Equipment Manufacturers

Benefits of Construction Equipment Technologies and their Impact on Society

CONTEXT®

The following report aims to provide an overview of key technologies benefiting a variety of stakeholders

The following report distills the findings from multiple stakeholder interviews conducted by AEM, outlining how construction equipment technologies have **advanced** the construction industry and **benefited** a wide range of stakeholders, from contractors, to owners, to society as a whole.

We have identified four construction equipment technologies that have played a critical role in advancing the industry, leading to benefits in:

① Productivity & Performance

② Planet & Environment

③ People & Safety

The report is structured as follows:

① A **brief overview of the construction industry** that demonstrates the industry's complexity and size at a high level.

② Key statistical highlights of **improvements seen in the construction industry** owing to construction equipment technologies.

③ Outline of **four key construction equipment technologies** identified by stakeholders as being critical in advancing the overall construction equipment landscape.

④ In-depth analysis of the four construction equipment technologies, their individual benefits, and case studies about their scale of impact on a variety of stakeholder groups.

Report Structure

1. Overview of the construction industry
2. Contributions of construction equipment technologies
3. Construction equipment technologies
4. Technology profiles and case studies

The report intends to inform a broad audience about the direct and indirect benefits to stakeholders due to the advancements in the industry

PROJECT METHODOLOGY

Stakeholder workshops

Engage several participants such as OEMs, technology providers and Tier 1 component suppliers.

AEM conducted round table discussions on the key developments in construction equipment technologies and how they have impacted the industry and society at large.

BENEFITS OF CONSTRUCTION TECHNOLOGY REPORT

Technologies impact modern construction equipment and the benefits they provide to a broad set of stakeholders

Broad literature review

A review of case studies, academic literature, economic impact studies, industry statistics, company literature, and product testing results.

A review of modern construction technologies, future technologies, legislation, and product roadmaps.

Condense industry expert insights into the first and second-order benefits of modern construction equipment technologies.

Purpose

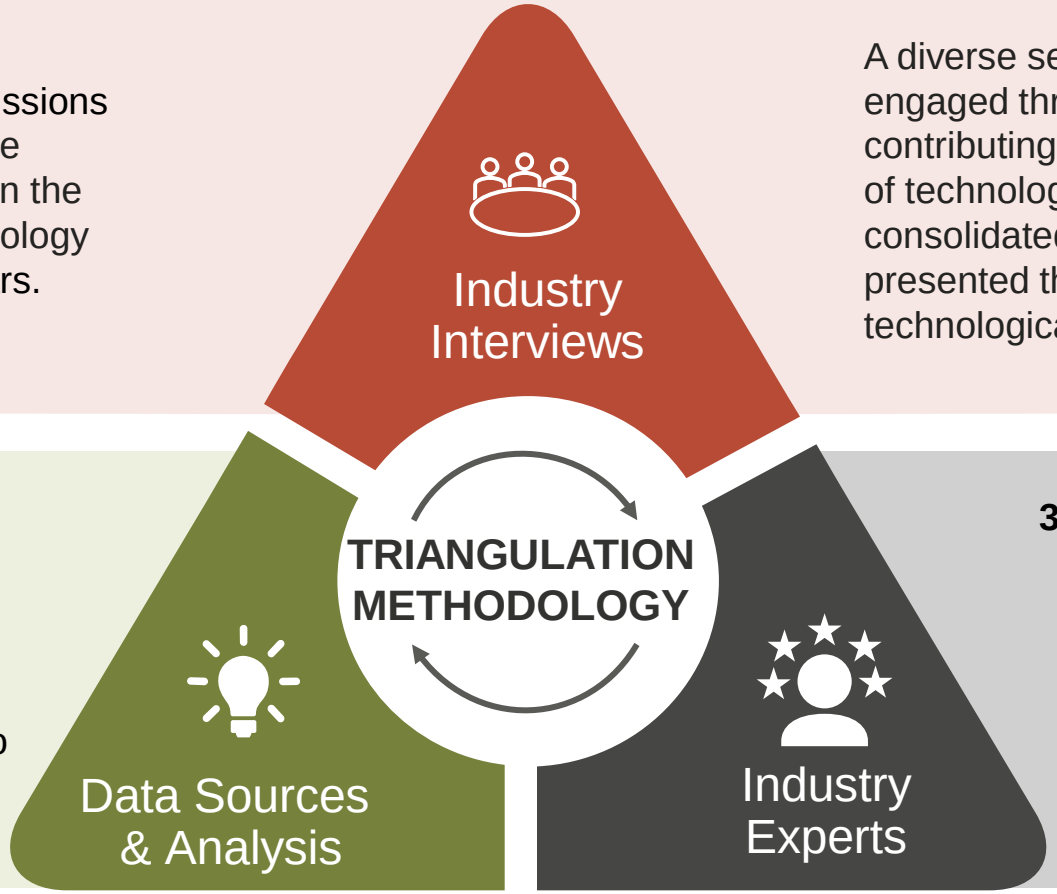
Inform the public of the advancements made in the industry and influence positive & supportive public policy outcomes.

In order to align on the benefits of each technology, the study triangulated numerous data sources, industry stakeholder interviews, and subject matter experts

Three key sources of information were leveraged to develop this report:

1. **Industry interviews**:
A series of 3 roundtable discussions were conducted to align on the overarching advances made in the construction equipment technology industry over the last ~30 years.

A diverse set of industry stakeholders were engaged throughout this process to ensure all contributing technologies were captured. The list of technologies and their benefits were then consolidated to include only those that presented the minimum overlap of benefits and technological functionality.



2. **Data sources and analysis**:
Public and proprietary data sources were leveraged to measure and quantify the benefits that construction technologies have provided to people, productivity, and the planet.

3. **Industry experts** with decades of experience in the construction equipment industry were engaged throughout the process to provide additional background, provide industry wide estimates, and fill gaps in information.

Overview of the Construction Industry

The construction industry is large, complex, and diverse

The construction industry's scope is massive, spanning all domains related to infrastructure and buildings.

There are four main categories of construction projects:

Single & multi-family homes

Offices & warehouses

Factories or large-scale production facilities

Roads, bridges, airports, and systems that provide utilities such as power and water

Tend to be privately owned

Tend to be publicly owned

Construction is a vital part of the economy, promoting both jobs and growth

The construction industry is a **MAJOR CONTRIBUTOR** to the US economy. The industry is deeply intertwined with the broader economy and is one of the largest consumers of the manufacturing, mining, and other service industries.

Statistical highlights of the overall construction industry

4.3%
of the US GDP[1] in 2023

$1.8 T
US construction spending[1] in 2023

3%
Of the US workforce[2] in 2023

Over the last 30 years, there have been conservatively, over 40 million homes built[3], over 700,000 lane miles of roads paved and rehabilitated[3], thousands of miles of sewers, potable water pipes, utility power lines, and internet cable installed, leading to improvement in countless people's lives.

[1] US Census data, [2] Bureau of Labor Statistics, [3] AEM Model, US housing STARTS report, Census data

Contribution of Construction Equipment Technologies

Construction equipment technologies have played a crucial role in improving safety and environmental outcomes for the industry

The construction industry is heavily dependent on the advances made by the **CONSTRUCTION EQUIPMENT TECHNOLOGIES INDUSTRY**, as without them, most of the infrastructure we rely on today would not be possible.

Over the last 30+ years, the construction equipment technologies industry has enabled many improvements within the broader construction industry, such as

79%
Reduction in construction worksite **injuries**[1]

83%
Reduction in construction worksite **fatalities**[1] associated with equipment

96%
Reduction in NOx and particulate emissions[2] per gallon of diesel consumed

~13%
Reduction in CO_2 emissions[3,4] per machine hour

+

Additional improvements to productivity, machine utilization, and others are outlined in further detail in this report.

[1] Bureau of Labor Statistics OSHA, [2] EPA and EU nonroad emissions regulations, [3] Industry estimates [4] 13% reduction of CO_2 emissions per machine hour of today's tier 4F engines when compared to a comparable Tier 1 engine, stemming from an improvement in fuel efficiency

Modern construction equipment technologies enable several direct and indirect benefits to stakeholders

Construction equipment technologies have advanced machine safety and efficiency, leading to direct and indirect benefits to a broad set of stakeholders

	1. Productivity & Performance	2. Planet & Environment	3. People & Safety
Direct outcomes[1] *(Quantifiable)*	– Modern equipment can achieve **millimeter grade accuracy**, which leads to more efficient use of materials. – This improved accuracy is allowing operators to more closely **adhere to project specifications**, thereby reducing variance from original designs. – Remote diagnosis of machine problems help **prevent costly down time** that could delay projects considerably.	– Today's efficient engines emit far lower **NOx and diesel particulate matter** than their predecessors, greatly improving overall air quality outcomes. – **Engines are more fuel efficient** than their comparable predecessors, allowing for more work done per gallon of diesel consumed. – The accuracy and precision achieved from modern equipment **eliminates**, to a large extent, the need for **rework**. As such, **machines are running less for each job completed.**	– **Reduction in worksite injuries and fatalities** over the last 30 years relating to construction equipment use. – Novice operators now take less time to **"get up to speed"** when being trained to use new machinery. – Operators find that they can work longer hours with **lower fatigue and reduced job-related errors.**
Indirect outcomes[1]	– Contractors can **undertake more complex work** as a result of the capabilities of advanced machinery.	– With an ever-increasing optimization of material use, **less concrete, asphalt, and soil aggregates are required for the same job**. In the long run, this reduces the total volume of these inputs needed, and presents a significant environmental benefit.	– Construction machinery is **quieter** today than its predecessors and tends to be less disturbing to residents. – The increased speed with which work is being done today **minimizes disruption** to communities and area/road closures.

[1] Output from stakeholder roundtable discussions

Construction Equipment Technologies

Four construction equipment technologies have been crucial in enabling the benefits outlined previously, and they have continued to evolve over the last 20-30 years

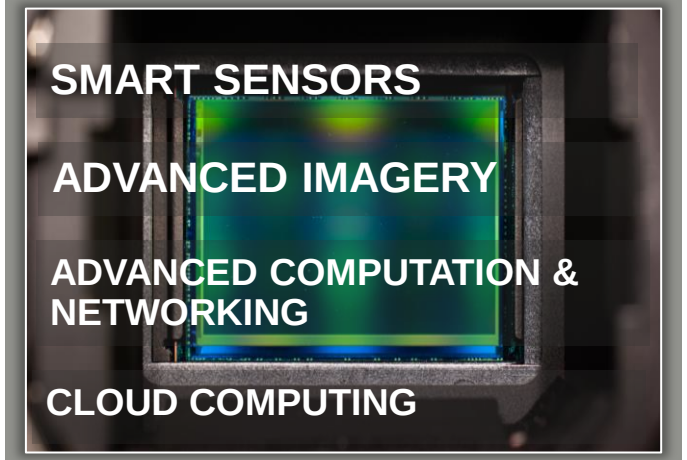
	DESCRIPTION
Machine & Grade Control	Machine control solutions determine a machine's current position on the earth and compare it with the engineered design. Using data from satellites, total stations, and 3D digital models, the technology ensures that machine operators can accurately position machinery, check grade, automate equipment functions, and collect data.
Engines & Drivetrains	Since the Environmental Protection Agency (EPA) instituted the tiered, non-road engine regulations in 1996, OEMs have innovated to make today's diesel engines and drivetrains more fuel efficient, emit less particulate matter, and be quieter than their predecessors.
Digital Control Systems	Digital control systems is an all-encompassing term for the suite of technologies that automate processes and tasks of operation on a piece of equipment. These technologies make operating the machine easier by using sensors and controls to reduce the number of variables the operator must control.
Machine Telematics	Telematics are the set of technologies used to remotely monitor and optimize machinery assets. Some of the variables tracked include location, use time (uptime), diagnostic trouble codes, fuel consumption, and operating behavior.

The smooth functionality of the outlined modern construction technologies are enabled by a suite of other innovations

The advancement of construction equipment technologies is enabled by the evolution of the supporting hardware and software architecture in other industries.

The advances made in these technologies are deeply intertwined with the advances made in construction equipment technology.

Enablers



Several advances in hydraulics, electrical actuators, and motors, among others.

Impacts Observed

Impacts of advances in other industries are observed in the four construction equipment technologies identified:

- Machine & Grade Control
- Engines & Drivetrains
- Digital Control Systems
- Machine Telematics

Note: *Alternative energy sources for powertrains like electric, hybrid, hydrogen fuel cell, methane, and others have been excluded from the report.*

Each technology directly or indirectly impacts productivity, people, and the planet

	Productivity & Performance	Planet & Environment	People & Safety
Machine & Grade Control **How benefits are achieved**: Location data and millimeter grade accuracy	✓	✓	✓
Engines & Drivetrains **How benefits are achieved**: Lower diesel particulate matter, improved fuel efficiency, and lower noise profile	✓	✓	✓ (indirect)
Digital Control Systems **How benefits are achieved**: Automated processes and tasks of operation	✓	✓ (indirect)	✓
Machine Telematics **How benefits are achieved**: Real-time diagnostic data, location data, advanced analytics, and prescriptive maintenance.	✓	✓	✓

Key

✓ **Direct benefit**: Refers to an immediate impact made by the technology seen and felt in real time.

✓ **Indirect benefit**: Refers to a second order impact seen as a result of using the technology over a longer period.

To evaluate the benefits of modern construction equipment technologies, the report aggregated information from stakeholder discussions, published literature, subject matter experts, and data analysis

How exactly the report approaches the impact of each technology across the three main benefits

	Productivity & Performance	Planet & Environment	People & Safety
Machine & Grade Control **How benefits are achieved**: Location data and millimeter grade accuracy			
Engines & Drivetrains **How benefits are achieved**: Lower diesel particulate matter, improved fuel efficiency, and lower noise profile			
Digital Control Systems **How benefits are achieved**: Automated processes and tasks of operation			
Machine Telematics **How benefits are achieved**: Real-time diagnostic data, location data, advanced analytics, and prescriptive maintenance.			

Key

 Input from stakeholder engagement

 Input from industry experts

 Data analysis & modeling

Impact modeled at an industry level

Qualitative and quantitative case studies

Technology Profile & Case Study

Machine & Grade Control

Machine and grade control technology have become an integral part of machinery engaged in earthmoving and paving applications

Machine control solutions determine a machine's current position on the earth and compare it with the engineered design. Using data from satellites, total stations, and 3D digital models, the technology ensures that machine operators can accurately position machinery, check grade, automate equipment functions, and collect data.

Some of the benefits to stakeholders include[1]

1

Improved accuracy & quality

By using positioning sensors and displays, grade control allows the operator to achieve a clearer reference between the position of the machine bucket or blade and the design surface. This reduces the risk of human error while simultaneously improving accuracy. Modern total station systems can achieve millimeter-level accuracy without having to compromise on the speed of completing grading tasks.

2

Ease of operation

The technology allows for data-driven decision-making as opposed to other traditional methods, like the skill and experience of the operator, which is more variable and highly subjective. As a result, machine control can increase the machine operators' productivity and accuracy. This enhancement in ease of use not only makes training novice operators easier, but also decreases the time taken to reach full productivity.

3

Savings on fuel and materials

Over time, improvements in accuracy prevent avoidable rework and unnecessary use of materials as well as accumulation of machine hours, which leads to savings across the board—for contractors, project owners, and ultimately, the end user. Industry estimates suggest that savings from the use of modern machine control technologies reduce material consumption between 10-20% in comparison with legacy machines without this technology.

[1] Insights gained from stakeholder engagement

The savings on material use by construction equipment fitted with grade control technologies impact everyone, down to the taxpayer

The amount of concrete and asphalt SAVED on public road construction projects each year from using machine and grade technologies is **enough to pave a 2-lane highway from Chicago to Phoenix.**

Improvements in accuracy and reduction in re-work from the use of machine control on public road construction and maintenance have led to

- A **10-20% savings in material costs**[1] from an improvement in overall accuracy of grading jobs using grade control.
- These gains **saved taxpayers approximately $3.6b**[2] in material costs associated with public road construction projects in 2022 alone.

[1] Industry expert estimates, [2] AEM Model, Census data, Industry expert estimates

Technology Profile & Case Study

Engines & Drivetrains

Over the last 27 years, OEMs and Tier 1 component suppliers have driven innovations in engine and drivetrain efficiency, thereby reducing the environmental impact of construction machinery

Since the Environmental Protection Agency (EPA) instituted the tiered, non road engine regulations in 1996, OEMs and Tier 1 component suppliers have innovated to make today's diesel engines and drivetrains more fuel efficient, emit less Diesel Particulate Matter (DPM), and quieter than their predecessors.

Some of the benefits to stakeholders include[1]

1 More fuel efficient

As OEMs and Tier 1 component suppliers in the construction equipment industry have collaborated to meet and exceed the DPM and emissions requirements set by the EPA, the engines and drivetrains installed in modern machines have subsequently demonstrated increasingly efficient fuel burn. As a rule of thumb, the transition from one emission tier to the next brings with it an efficiency gain of ~3-5%[2] for any one particular horsepower class of engines. Since 1996, we have seen 4 distinct emissions tiers, and as a result, today's modern machines today are 11-15% more fuel efficient than they were in 1996.

2 Increased power density

Increases in power density result from high-pressure common rail fuel delivery systems and electronically controlled fuel injection coupled with turbochargers. This results in engines pumping out more power per cubic centimeter of displacement. Subsequently, engines with lower displacement can be used to perform the same job. This reduces weight and leaves more room available for advanced cooling systems and engine aftertreatment systems, which are required to meet current emissions requirements.

3 Significantly lower particulate emissions

The emissions tiers initially instituted by the EPA primarily sought to reduce DPM. Today's diesel engine emits 96.3%[3] less NOx and approximately 11-15% less CO_2 per hour of use than their counterparts in 1996. The technical developments responsible for the drastic emission reductions include aspects ranging from the fuel to the engine's combustion system down to the exhaust aftertreatment.

[1] Insights gained from stakeholder engagement, [2] Industry estimates, [3] AEM, EPA

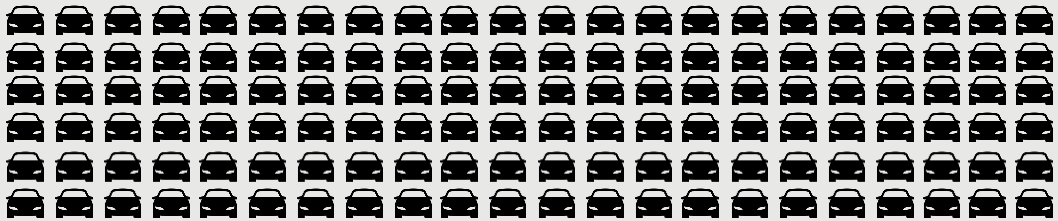
Today's engines and drivetrains operate more fuel efficiently while emitting less DPM into the environment as a result of decades of innovation from OEMs and Tier 1 component suppliers

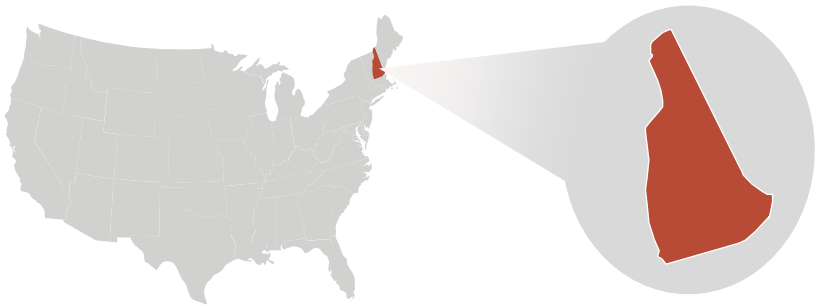
What the latest efficient engines have helped save on total fuel use in North America

The fuel saved from improvement in efficiency of today's engines and drivetrains is roughly the equivalent to…

Removing 1,350,000

Cars off the road permanently[1]





That is equal to the number of cars registered in the state of New Hampshire

How do modern engines enable this?

Since the EPA instituted the tiered, non road engine regulations in 1996, OEMs have innovated to make today's diesel engines and drivetrains more fuel efficient, emit less DPM, and be quieter than their predecessors. Today's tier 4 engines are roughly 11-15%[2] more fuel efficient per machine hour, thereby able to do more work per gallon of fuel consumed. This improvement when scaled up across all machines in use today results in significant benefits seen and felt throughout society.

[1] Off Highway Research, Industry estimate, Industry experts, Context analysis, [2] Industry estimates

The drastic reduction in diesel particulate matter has improved air quality for all

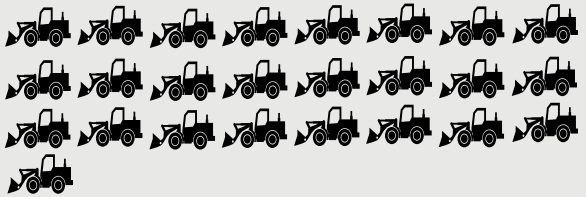
How much does a wheel loader emit today in comparison to its predecessor?

The 96%[1] reduction in NOx and DPM emissions would roughly mean that…

Emissions from **ONE** Wheel loader in **1990**

=

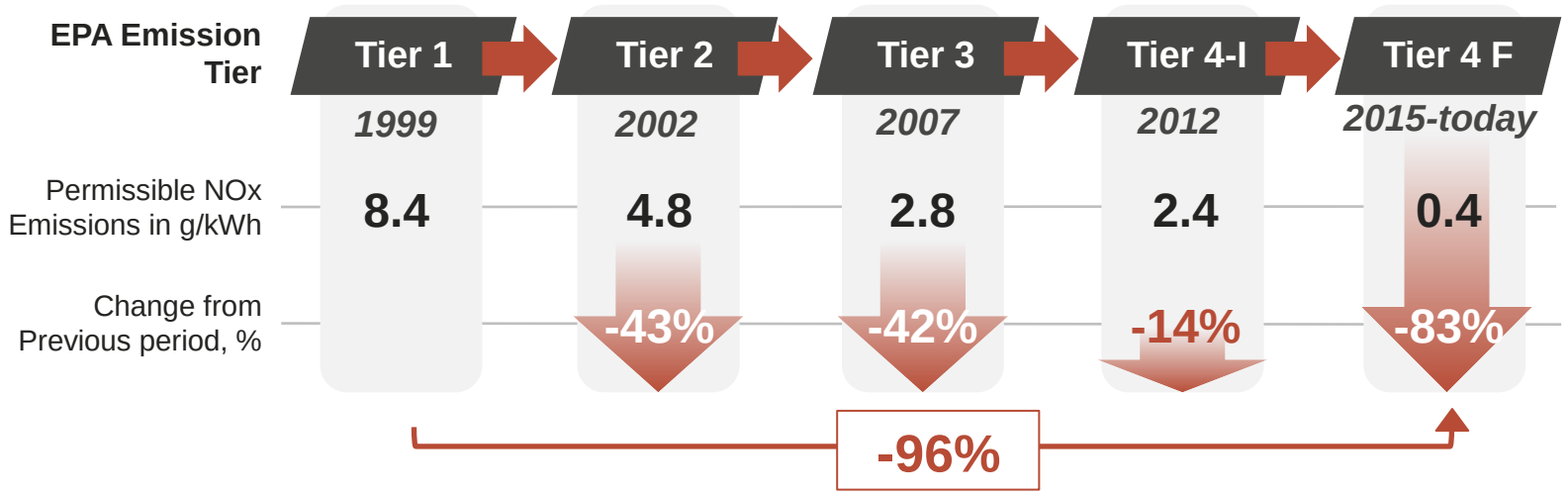
Emissions from **25** Wheel loaders in **2020**



Every emissions tier has brought with it a **LARGE REDUCTION IN NOx EMISSIONS FROM ITS PRECEDING TIER**.

Over time, these improvements have compounding; today, the average diesel engine emits 96% less DPM and NOx gases

For the average 100 HP off-highway diesel engine[1]…



[1] AEM, EPA

Technology Profile & Case Study

Digital Control Systems

Digital control systems improve operator working conditions through the automation and standardization of otherwise routine tasks

Digital control systems is an all-encompassing term for the suite of technologies that automate processes and tasks of operation on a piece of equipment. These technologies make operating the machine easier by using sensors and controls to reduce the number of variables the operator must control.

Some of the benefits to stakeholders include[1]

1

Worker safety & health

The automation of repetitive tasks that would have otherwise required operator control yields many benefits to the operator. For example, buckets on wheel loaders can be programmed and customized for specific actions on the dump lever through a digital control system. These types of conveniences enable the following:

- Reduced operator fatigue by automating repetitive tasks.
- Reduced stress levels and ergonomics.
- Reduced excessive/unnecessary physical labor.

2

Improved functionality & versatility

The digitization of tasks that were previously dependent on manual operation allows for more consistent task completion.

- Controls tuned to operators' specs improves speed and ease of use.
- Reduced complexity allows for fewer workplace errors and short operator adoption periods.
- Novice operators can be trained more easily into efficient and productive operators.

3

Servicing & maintenance

Given the digital and connected nature of these systems,

- OEMs and dealers can diagnose and solve a host of problems without having to send a technician to the site.
- Over the air updates and software patches allow for faster and longer design cycles as a result of not having to make small updates to hardware, thereby freeing up internal resources.

[1] Insights gained from stakeholder engagement

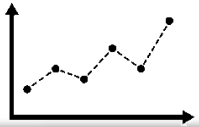
Because of digital control systems, novice operators can be more accurate and upskilled faster and more effectively than before

The What

Managers and supervisors don't have to wait as long to find an experienced operator to perform a particular job.

A relatively novice operator with adequate machine sensibilities can be placed in the machine with reasonable confidence, knowing that there are control systems on the machine that can compensate for mistakes that the operator might make.

There are **several technologies** on-board machines today that have the ability to **automate processes and tasks of operation** to reduce the degree of operator-induced variation.



The How Much

From test results[1] conducted that compared novice and experienced operators in manual mode vs. digitally assisted mode:

NOVICE OPERATORS ARE

>80% more accurate

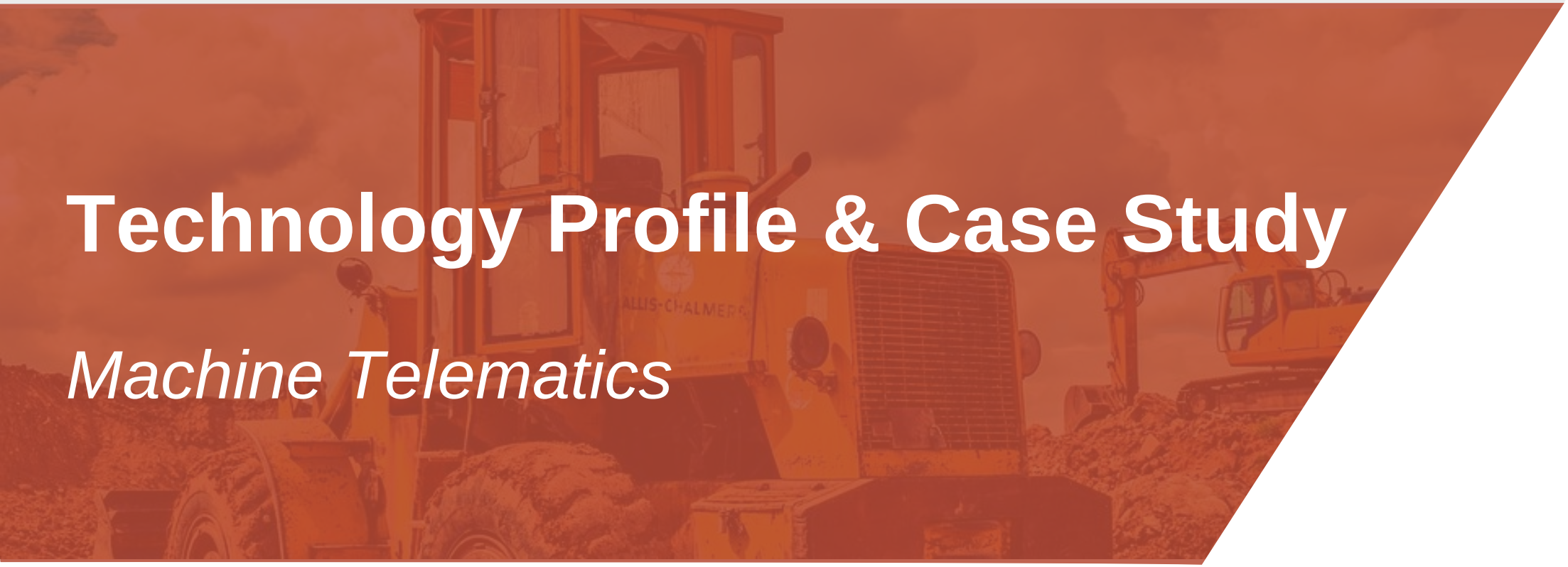
>30% quicker

EXPERIENCED OPERATORS ARE

>50% more accurate

>10% quicker

[1] Industry data



Technology Profile & Case Study

Machine Telematics

Technology, similar to that in the average smartphone, is the basis of modern digital workflows that make fleets more efficient and productive

Telematics are the set of technologies used to remotely monitor and optimize machinery assets. Some of the data collected include location, use time (uptime), diagnostic trouble codes, fuel consumption, and operating behavior.

Some of the benefits to stakeholders include[1]

1

Reduced machine downtime & maintenance costs

Machine telematics enable operators to monitor machine utilization in real time, identify operators that require training, optimize machine uptime, reduce idle-time fuel burn, and run real-time machine diagnostics. As a result, project downtime is reduced, leading to fewer delays in project timelines.

2

Effective fleet management

These systems enable fleet managers to ensure that the right equipment is in the right place, at the right time, and used by the right operator, thus greatly reducing misuse and theft of machines. Location data also allows for an increased awareness of the safety of people, machines, and structures around the vehicle through geofencing capabilities that modern telematics systems come equipped with.

3

Prescriptive & predictive machine diagnostics

Today's telematics systems can gather diagnostics of the engine and other components of the machine. This reduces the reliance on standard maintenance schedules and allows for scheduled downtime. Additionally, fleet owners benefit from the significant savings from avoiding accelerated depreciation on the machine in the long run.

[1] Insights gained from stakeholder engagement

Machine telematics, when comprehensively adopted across all construction equipment, can save millions of gallons of diesel each year

What telematics has helped save on total fuel use in North America

The fuel saved from reducing nonproductive idling across all machines in North America due to the effective use of telematics is equivalent to…

25,000

One-way flights from NYC to Chicago[1]

This is equivalent to flying around the world 800 times

How does telematics enable this?

When a machine is not under load with the engine still running at low RPM, it is considered idling. However, not all idling is nonproductive. Anywhere from 10-30% of the fuel consumed by construction machinery is from nonproductive idling. By using telematics systems, fleet machinery idling time can be reduced significantly – between 10 and 15%. A telematics system provides fleet managers with tracking information, location data, engine status, and usage analytics. This data is leveraged to identify efficiencies for reductions in nonproductive idling, thereby reducing fuel use and costs as well as repairs and maintenance costs.

[1] Off Highway Research, Industry estimates, Industry experts, Context analysis

Key Next Steps for the Industry

As innovation accelerates in the coming years, OEMs, technology providers, and tier 1 component suppliers will continue to develop the next generation of technology that will support contractors, owners, and society as a whole

Additional support comes through positive and supportive public policy, including:

- ★ **Strategic use of state and federal funding to create efficiencies and long-term return on investment.**
- ★ **Incentives to drive adoption of new technology throughout the construction industry.**
- ★ **Education of stakeholders on benefits of construction equipment technologies and their significant impact.**
- ★ **Assurance that the enabling infrastructure is in place to support implementation of technology.**

The adoption and implementation of next generation technology, along with existing construction equipment technologies, will drive additional benefits in productivity & performance, planet & environment, and people & safety.

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