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Past and Future of Construction Equipment—Part IV

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Abstract: The development of construction equipment has followed the major changes in global transportation. In 1420, Giovanni Fontana was dreaming of and diagramming dredging machines. Development of the steam shovel was driven by a demand for an economical mass excavation machine to support the era of railroad construction. The Cummins diesel engine was developed in the early 1900s as the road-building phase of transportation construction began. In the short term, the basic machine frame will not change, but productivity, accuracy, and utility should improve because of enhancements. Machines will evolve into a mobile counterweight driven by an energy-efficient powerplant. This mobile counterweight will serve as a work platform for an array of hydraulic tools, and it will have synthesized computers that instantly communicate by satellite with distant management teams reporting diagnostics, production, and position.

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Foreword

In 1975 the Construction Division of ASCE celebrated its founding 50 years earlier in 1925. At that time a series of papers appeared in the *Journal of the Construction Division* discussing 50 years of engineered construction. That series included three papers [(Douglas 1975; Klump 1975; Larkin and Wood 1975)] discussing the *past and future of construction equipment*: All three papers are discussed in this paper. In honor of ASCEs 150th anniversary, the title and subject matter of this paper follow from these earlier papers, produced 27 years ago.

The Dreams

The development of construction equipment has followed the major changes in global transportation. When travel and commerce were by water systems, builders dreamed of machines to aid in the dredging of ports, rivers, and canals. As early as 1420—72 years before Columbus discovered America—the Venetian Giovanni Fontana was dreaming of and diagramming dredging machines. Leonardo da Vinci designed such a machine in 1503. A few of these machines were actually built, but power was still by the muscle of man: the power source for one of these machines was a lonely runner on a treadmill.

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In 1852, when the American Society of Civil Engineers and Architects (later the ASCE) was incorporated, construction in the United States was changing from canal building to railroad construction. The Middlesex Canal, which connected Boston to the Merrimack River at Lowell, had been in service since 1803, but in 1853 the Boston & Lowell Railroad superseded it. The canal transportation systems, which had played such an important role in the development of the country, were about to be succeeded by the railroads, but construction, be it building canals or railroads, was still achieved by the brawn of man and beast.

In 1843 Caleb Eddy, agent of the Middlesex Canal corporation, wrote. ''The inventions and ingenuity of man are ever onward, and a new cheap and more expeditious mode of transportation by steam power has been devised which seems destined to destroy that which was once considered invulnerable.'' Eddy had a good understanding of how better and cheaper energy sources—technology—affected the canal. The technology of capturing energy for beneficial use is a major driver in equipment change.

Steam Power Machines

The first practical power-shovel excavating machine was built in 1835. William S. Otis, a young civil engineer with the Philadelphia contracting firm of Carmichael & Fairbanks, designed this ingenious machine. The first ''Yankee Geologist'' machines, as they were called, were put to work in 1838 and 1841, respectively, for railroad work in Massachusetts and New York. Cohrs (1997) reports that only seven of these excavators were ever built, but Anderson (1980) says that the most accurate estimate of the number of machines manufactured is 20. The Anderson number is for the time period from 1840 to 1860; Cohrs does not state a time period. Anderson also adds that every recorded user was a business associate of Otis or his uncle, Daniel Carmichael. It is known that four ''Yankee Geologist'' machines went to Russia to work on the St. Petersburg–Moscow Railroad. George W. Whistler may have had a hand in this interesting transaction; in 1842 he had

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moved to Russia after agreeing to manage construction of the St. Petersburg–Moscow Railroad. Whistler was a West Point-educated engineer who surveyed many of the early railroads and actually supervised the first laying of track for a passenger railroad in the United States (Hill 1957).

Another shovel went to England, where it was put to work on a railway in Essex. Anderson leaves the impression that Carmichael had some part in the Russian and English work, but the relationship may really be a connection between Carmichael and Whistler. When working with the Baltimore and Ohio Railroad (B&O) and still a lieutenant in the Army, Whistler was sent to England by the B&O to examine railroad construction there, so he had personal railroad connections in that country. As an interesting note, the second Otis excavator was employed in Canada until 1905.

Otis's patent application stated

> I . . . have invented certain improvements in the apparatus for and mode of excavating earth for the construction of railroads, canals, or other purposes where excavation may be necessary which I effect by means of certain appendages to a scraper of the ordinary construction, which scraper is to be worked by a crane and is to take the earth immediately from the banks from which the excavations are to be made . . . .

He went on to describe how by a system of pulleys to move its arms and bucket the load could be taken up by the scraper, raised by the crane, and turned to be dumped. But he made only two patent claims: (1) the principle of the power thrust of the shovel handle; and (2) a type of friction clutch on the power transmission to the handle. The technology change was related to energy and energy transmission.

Continued development of the steam shovel was driven by a demand for an economical mass excavation machine. An era of major construction projects began in 1880. These projects demanded machines to excavate large quantities of earth and rock. In 1881, Count Ferdinand de Lesseps's French company began work on the Panama Canal. Less than a year earlier, on December 28, 1880, the Bucyrus Foundry and Manufacturing Company, of Bucyrus, Ohio, had been issued its certificate of incorporation. Bucyrus became a leading builder of steam shovels, and 25 years later, when the Americans took over the canal work, the Bucyrus Company would be a major supplier of steam shovels for that effort. Other large projects undertaken in the 1880s that required excavation machines included the Chicago Drainage Canal. The Chicago Canal alone involved moving 30,580,000 m^3 (40,000,000 cu yd) of earth and rock excavation.

However, the most important driver in excavator development was the railroad. In the first 50 years of ASCE's existence, about 80% of today's railway network worldwide came into being. Between 1885 and 1897 approximately 112,630 km (70,000 mil) of railway were constructed in the United States. William Otis developed his excavator machine because the construction company Carmichael & Fairbanks, for which he worked and in which his uncle, Daniel Carmichael, was a senior partner, was in the business of building railroads.

The Bucyrus Foundry and Manufacturing Company came into being because Dan P. Eells, a bank president in Cleveland, was associated with the Lake Erie and Western Railway, the Chicago and Saint Louis Railway, and the Ohio Central Railroads. Eells saw an opportunity to profit from a company that produced railroad equipment, and that is what the company did for the first 4 years. But in 1882 the Ohio Central Railroad gave the new company its first order for a steam shovel, and sales to the Northern Pacific Railroad (two machines) and to the Savannah, Florida, and Western Railroad soon followed.

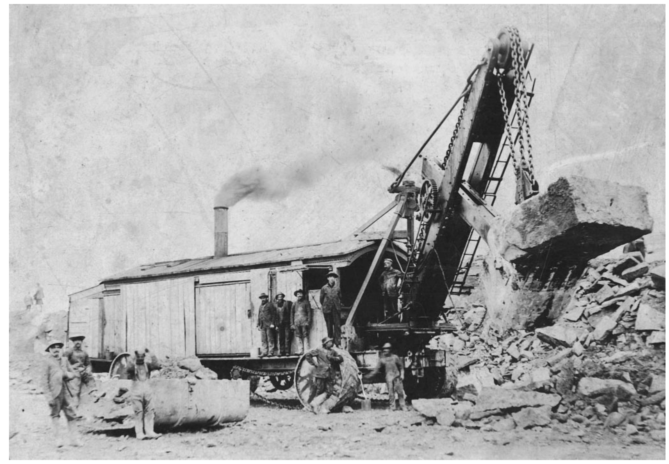

Fig. 1. Early 20th century steam shovel (note this machine is mounted on steel traction wheels)

The first Bucyrus excavator was shipped on June 3, 1882, to the Northern Pacific Railroad. In May 1883 the company exhibited a shovel at the National Exposition of Railway Appliances in Chicago.

Fig. 1 shows an early 20th century steam shovel mounted on steel traction wheels. Most machines of this period were still mounted on a railway carriage.

Internal Combustion Engines

By 1890 courts of law in Europe had ruled that Nikolaus Otto's patented four-cycle gasoline engine was too valuable an improvement to keep restricted any longer. Following the removal of that legal restraint, many companies began experimenting with gasoline-engine-powered carriages. The Best Manufacturing Company (predecessor to Caterpillar Inc.) demonstrated a gasoline tractor in June of 1893.

Between 1900 and 1911 the Bucyrus Company had conferences with the General Electric Company concerning the use of electrical devices and power for large shovels. The Bucyrus Company came to the conclusion that such a power source was not yet practical. Conversely, Bucyrus did conclude that the only other power source alternative was the internal combustion engine.

The first application of the internal combustion engine to excavating equipment occurred in 1910, when the Monighan Machine Company of Chicago shipped a dragline powered by a 37.2 kW [50 horsepower (hp)] Otto engine to the Mulgrew-Boyce Company of Dubuque, Iowa (Anderson 1980). Bucyrus shipped a gasoline-powered placer dredge to the Yuba Construction Company of Soloman, Alaska, in 1911.

Henry Harnischfeger brought out a gasoline-engine-powered shovel in 1914, and following World War I, the diesel engine was put into excavators as the power source. The Cummins diesel engine had been developed in the early 1900s by a self-taught mechanic named C. L. ''Clessie'' Cummins. Working out of an old cereal mill in Columbus, Indiana, Cummins's first engine was a Dutch-designed, 4.5 kW (6 hp), farm-type diesel. The Cummins engine soon became popular in other applications, including power shovels. Warren A. Bechtel, who first entered the construc-

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Fig. 2. Photograph with Dwight D. Eisenhower's description from personal collection of Dwight D. Eisenhower (Courtesy, Dwight D. Eisenhower Library)

tion field in 1898 in Oklahoma Territory and quickly built a reputation for successful railroad grading, pioneered the use of motorized trucks, tractors, and diesel-powered shovels in construction.

The Erie Steam Shovel Company (later consolidated with the Bucyrus Company) deserves special attention as a machine innovator. Erie saw a need for an excavation machine designed especially for building construction and in 1914 produced a full-revolving steam shovel equipped with a 0.57 m^3 (3/4 cu yd) dipper. This was followed by a 0.38 m^3 (1/2 cu yd) version in 1916. These machines filled a market niche, but what made them different was that Erie fabricated all parts with jigs and templates. Interchangeable parts were part of Erie's manufacturing plan.

Erie also noted the advantages of other power sources for its machines and first experimented in 1925 with a 0.76 m^3 (1 cu yd) gas-plus-air excavator combining a gasoline engine, an air compressor, and air-operated motors. The price of this machine was higher than that of either steam or gasoline models offered by other manufacturers. So in 1926 Erie began changing its complete line of machines to gasoline. The change was difficult, but once the line of four machines from 0.38 m^3 (1/2 cu yd) to 0.96 m^3 (1 1/4 cu yd) was in place the results were phenomenal for Erie's sales (Anderson 1980).

In the winter of 1922–1923, the first gas-powered shovel was brought to Connecticut, and in the spring of 1923, it was employed on a federally aided road construction project running from Litchfield to Torrington. The third phase of transportation construction had begun. Contractors needed equipment for road building. In 1919 Dwight D. Eisenhower, as a young army officer, took an Army convoy cross-country to *experience* the condition of the nation's roads (Fig. 2). But as the country began to improve its road network, World War II intervened and road building came to a near halt as the war unfolded.

Large Projects as Incubators for Machine Innovation

Large construction projects provide a fertile test bed for equipment innovation. William Mulholland rode on horseback into Los Angeles in 1877 and proceeded both to better himself and to contribute to the city he loved. He passed from ditch tender to straw boss, to foreman, to superintendent learning construction. Later, as city engineer, Mulholland directed an army of 5,000 men who labored for 5 years to construct the Los Angeles Aqueduct, which stretches 383 km (238 mil) from the Owens River to Los Angeles.

Los Angeles Aqueduct

In 1908 the Holt Manufacturing Company (the other predecessor to Caterpillar Inc.) sold three gas-engined caterpillar tractors to the city of Los Angeles for Mulholland to use in constructing the Los Angeles Aqueduct. Besides crossing several mountain ranges, the aqueduct passed through the Mojave Desert, a severe test site for any machine. The desert and mountains presented a challenging test for the Holt machines, but Benjamin Holt viewed the entire project as an experiment and development exercise (Leffingwell 1997).

Holt found that cast-iron gears wore out very quickly from sand abrasion, so he replaced them with steel castings. The brutal terrain broke suspension springs and burned up the two-speed transmissions in his tractors, and the low gear was simply not low enough for the climbs in the mountains. Holt made modifications to the tractors both at his factory and in the desert. His shop manager Russell Springer set up repair facilities in the project work camps. Mulholland in his final report after completion of the project labeled the Holt tractors the only unsatisfactory purchase of the project, but Holt had developed a much better machine because of the experience.

Boulder Dam

In the years between the two world wars, one particular construction project stands out because of the contributions to equipment design that resulted from the undertaking. Boulder Dam (later named Hoover Dam) was the catalyst for major equipment developments. According to Larkin and Wood (1975), "On that project R. G. LeTourneau, the master of cutting and welding, eliminated the bolted connection and showed the true capabilities of welded equipment with cable operated attachments. This same man, through his numerous inventions and innovations in tractor/scraper design and manufacture, made possible the current earth-moving behemoths in use today." In the 1940s, those machines went on to build airfields around the world in support of the war effort.

Other developments that came from the Boulder Dam project included sophisticated aggregate production plants and improvements in concrete preparation and placement. The project was an enormous proving ground for new equipment and techniques. The use of long flight conveyor systems for material delivery was proven there. Henry Kaiser later put that knowledge to use in constructing Shasta Dam.

Three Significant Developments

After the war roadbuilding roared back, and in 1956 Eisenhower, now president, signed the legislation that established the interstate highway program. To support the roadbuilding effort, scrapers increased in capacity from 7.6 to 23 m^3(10 to 30 cu yd). With the development of the torque converter and the power shift transmission, the front end loader began to displace the old "dipper" stick shovels. Concrete batch and mixing plants changed from slow, manually controlled contraptions to hydraulically operated and electronically controlled equipment.

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High-Strength Steels

Up to and through World War II machine frames had been constructed with steels in the 210,000 to 242,000 kN/m^2 (30,000 to 35,000 psi) yield range. After the war, steels in the 280,000 to 311,000 kN/m^2 (40,000 to 45,000 psi) range with proportionally better fatigue properties were introduced (Klump 1975). The new high-strength steel made possible the production of machines having a greatly reduced overall weight. The weight of a 37,000 kg (40 t) off-highway truck's body was reduced from 11,000 to 7,200 kg (25,000 to 16,000 lb) with no change in body reliability.

Nylon Cord Tires

The use of nylon cord material in tire structures made larger tires with increased load capacity and heat resistance a practical reality (Klump 1975). Nylon permitted the actual number of plies to be reduced by as much as 30% with the same effective carcass strength, but with far less bulk or carcass thickness. This allowed tires to run cooler and achieve better traction and improved machine productivity.

High-Output Diesel Engines

Manufacturers developed new ways to coax greater horsepower from a cubic inch of engine displacement. Compression ratios and engine speeds were raised, and '' . . . the art of turbocharging was perfected to a practical level, resulting in a 10–15% increase in flywheel horsepower'' (Klump 1975).

Big Iron

In 1955 the Caterpillar Tractor Co. introduced its first D9 tractor, a 30,000 kg (33 t) machine with a flywheel rating of 213 kW (286 hp). Euclid followed in 1957 with the TC-12, a 325-flywheel kW (436-flywheel hp) crawler tractor. This iron monster used a separate engine to power each track. When they began developing the site for Dulles International Airport in Virginia, R. G. Le Tourneau was there with a 118,000 kg (130 t) capacity double-bowl scraper. Expansion and size also characterized wheel-loader machines, but the most significant improvement was the introduction of articulation in 1962, which increased the productivity of wheel loaders.

The Next 10 Years

Three professionals offering both contractor and equipment dealer viewpoints were questioned about trends in equipment technology and management. On the dealer side are Tom Bennet of RDO Equipment in Phoenix and Jerry Jung of Michigan CAT, Novi, Michigan. RDO is part of the John Deere dealer network. Mike Monnot of H. B. Zachry, headquartered in San Antonio, presents the contractor viewpoint. Each interviewee was asked the same three questions:

1. Will there be new types of construction equipment or advances in capabilities?
2. How will construction firms obtain the equipment: buy, rent, or lease?
3. How will equipment management change?

Fig. 3. Dozer blade laser control system demonstrated at 2001 Bauma, Munich, Germany

New Types of Construction Equipment

Bennet does not foresee any radically new equipment on the horizon. Everything he sees is merely refinement of the inventions of LeTourneau; earthmoving equipment will remain fundamentally the same.

Jung thinks that new attachments will mean improved utility for the contractor's fleet.

Monnot is in agreement with Bennet and Jung and does not foresee any new classifications of equipment, with the possible exception of equipment for fiberoptic cable installation.

Equipment technology or innovation can be categorized (Goodrum 2001) into three broad categories:

- *Level of control*: equipment advancements that transfer operational control from the human to the machine;
- *Amplification of human energy*: shift of energy requirements from the man to the machine; and
- *Information processing*: gathering and processing of information by the machine.

The responses of our professionals to this question are organized using this system of technology categorization.

Level of Control

Bennet believes safety will continue to be very important. Safety features and operator station improvements will evolve to compensate for the less experienced workforce available today and in the foreseeable future. Related to workforce quality is the proliferation of laser-controlled implements. Laser-guided equipment makes it much easier for inexperienced operators to perform fine-grade activities (Fig. 3).

Monnot says that even the lowly soil compaction roller will see improvement. New technology will allow the roller itself to

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measure the density of the fill and transmit that data via radio back to the project office. If proven accurate and successful, this development will reduce the number of inspectors required to perform compaction tests.

Further labor-saving improvements will include automated blade controls for finegrade operations and guidance systems for mass grading. The laser and global positioning satellite (GPS) guided systems will become more common and reduce the need for surveyors. All the grader or dozer operator will need to do is load the digital terrain model (DTM) into the on-board computer and then guide the machine where the display indicates. Machine position, along with cut or fill information, will be on a screen in front of the operator at all times. This may turn the operator's job into a video game.

Sound waves can also be used to control machine functions. Ultrasonic sound waves are emitted from a sensor unit and received back to the sensor. The principle is much the same as a ship's sonar. The time the sound wave takes to leave and come back is measured and the distance calculated by the computer. The computer keeps the machine on grade and controls the blade-lift functions. Finegrading a roadbase with a sonic blade control system requires only steering and travel speed input from the operator to keep the sensor over the grade wire or other fixed grade. One equipment group demonstrated a sound wave control system for asphalt pavers at the 2001 Bauma International Trade Fair.

At the Swiss Federal Institute of Technology in Zurich a shotcrete robot for tunnel work has been developed in collaboration with Master Builder Technologies (Girmscheid and Moser 2001). This shotcrete robot is equipped with a laser device that scans the surface of the tunnel on which the shotcrete should be applied. The computer then calculates a virtual surface based on the measured spherical tunnel surface. The virtual plane is located at a distance from the tunnel surface on which the nozzle of the shotcrete robot will be guided and held perpendicular to the rock surface. This makes the optimized application of shotcrete possible, with low rebound and high surface smoothness.

Ultimately, operators sitting in a machine cab may be eliminated altogether. Caterpillar is developing and testing automated rock hauling units for mining. These units are linked by radio to the office and tracked by GPS. The superintendent need only use a laptop to send the start signal, and the trucks do the rest, leaving the lineup at set intervals and following the prescribed course. The superintendent can track the progress of each machine on the computer; if a truck develops a problem, the situation is signaled to the superintendent for corrective action.

Amplification of Human Energy

According to Bennet all machine progress will be in equipment technology. There is a trend to all-hydrostatic drive machinery; transmissions and torque converters will become obsolete. However, Caterpillar is resisting the trend toward hydrostatic drive. As hydraulic systems and electronic controls improve, equipment operation will be simplified, which is a continuing trend that is already being experienced.

There will most likely be a trend to smaller and more versatile equipment. Such equipment is necessary for accomplishing reconstruction projects. Highway reconstruction is often performed within space-restricted single or double lane closures. The ability to work within a narrow space with small but multitooled equipment will be a real advantage.

There may come a time when the base machine is only considered a *mobile counterweight with a hydraulic powerplant*. The base machine will perform a variety of tasks through multiple attachments. This trend has started with hydraulic excavators and the many attachments available such as hammers, compactors, shears, and material-handling equipment. Wheel-loaders have seen the introduction of the tool-carrier concept. Along with the standard bucket, other attachments such as brooms, forks, and stingers are readily available to perform multitude of tasks on the jobsite. Other attachments will be developed, offering the contractor more versatility from a base investment.

Jung believes that there will not be any radically new equipment but there will be more and improved attachments available for existing equipment. Machines will become multifunctional. He feels that there will continue to be improvements to hydraulic systems and to the hydraulic power at the end of an excavator boom.

Information Processing

Monnot believes there will be continued refinements to on-board machine diagnostics. These will shorten troubleshooting and repair time. There will be expansion of tools such as the Caterpillar Electronic Technician (ET) and Vital Information Management System (VIMS) among all manufacturers and deeper into the product lines. Komatsu, for example, had an impressive display of their information management tool at the 2000 MineExpo in Las Vegas.

Safety is a major concern for these self-guided behemoths. Sensors scan all around the truck for potential problems. If an obstacle is encountered in the roadway larger than a basketball the lead truck stops and sends a signal to all the other trucks to stop. It also signals the superintendent where they are located so that someone can be dispatched to check the problem. It would be unlikely that the automated technology could be adapted to smaller construction equipment in the foreseeable future.

There is general agreement among those interviewed that nothing radical would be forthcoming in the foreseeable future. The basic machine frame will not change, but productivity, accuracy, and utility should improve because of enhancements.

Obtaining Equipment in the Future

Bennet sees equipment leasing becoming more popular now and in the foreseeable future, but it is his view that construction firms will continue to obtain equipment by all three of the traditional methods—buy, rent, and lease—but the breakdown for each is uncertain.

Tax Code

The tax code plays a major role in how a company will obtain and pay for equipment. If it is more advantageous to lease, that is what the contractor will do. Other factors are the company's cash flow and retained earnings. Both affect bonding capacity and the ability to bid new work.

Rental equipment is a very competitive market. Traditionally, a dealership would rent equipment more as a machine sales tool rather than as a supply source for a contractor's short-term equipment needs. It was hoped that the short-term rental would result in a machine purchase if the contractor was satisfied with the machine. Now, with the proliferation of major equipment rental firms, dealers have had to adjust their rental strategies. The rental firms have grown to the point of becoming quasi-dealers themselves. They provide parts and service for their equipment and have the purchasing power to negotiate competitive prices from

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the manufacturers. This has forced the dealerships to conduct their business more like a rental company.

Dealer Rental Strategy

Jung feels that there will be an increase in equipment rental and rent-to-own plans. Currently in the United States, rental equipment makes up on average 20% of a contractor's fleet. Contrast that number with Europe and Japan where, according to Jung, the rental equipment components of the fleet are 40 and 80% respectively. The current wisdom dictates that the United States will follow suit in the coming years. Dealerships will need to make adjustments to their rental strategy to ensure market share.

Types of Projects

Monnot feels that companies will rely more on lease-to-purchase plans as long as the tax code remains the same. However, companies need to carefully analyze their ownership costs each way: buy, rent, or lease. The proper decision is very dependent on the company's financial situation.

Companies will probably buy less large equipment unless more highway work is planned, bid, and let. New highway construction is essentially complete, and the market for large scrapers may taper off. No one wants to be stuck with a fleet of large and expensive yet obsolete equipment. Renting or leasing these types of equipment may make more sense in the future.

The general consensus seems to be that rental and leasing will increase in popularity, but the degree will be dictated by the U.S. tax code. Dealerships will need to adapt or be left behind by the equipment rental firms that are now in the market. Some manufacturers are already using the rental dealer network as a quasi-distributor network.

Equipment Management

The first aspect that Bennet sees is that equipment management will change based on shorter ownership periods.

Technological Advantage

Bennet believes equipment innovations will come to market at a faster rate, and as a consequence individual machines will experience productivity obsolescence sooner. That does not mean that the equipment will be ready for the scrap yard in 2 or 3 years, but that the technological advantage and therefore the competitive advantage will be gone. These 2- or 3-year-old machines will have a useful place in the secondary market; for example, farmers and small firms that cannot afford first-line equipment. Dealerships will expand guaranteed buy-back programs to allow for a predictable salvage value at the end of the machine's economic life. More accurate financial planning to include the equipment component will improve a company's success.

Maintenance—Technical Training Required

Maintenance will see many changes. There will be a move toward more dealer-performed service rather than self-performed service. Even today, says Bennet, the number of dealer technicians is increasing while the number of contractor mechanics is decreasing. With the equipment changing so rapidly, it is difficult, if not impossible, for a contractor technician to remain current without the technical training available to the dealer technician. Another factor encouraging this trend is the latest array of diagnostic tools and equipment available to dealer technicians. The combination of up-to-date factory technical training coupled with the latest diagnostic tools usually means shorter down time for the equipment and reduced repair cost.

Guaranteed maintenance programs will help the contractor manage the maintenance budget for the fleet. Under such a program, a set fee is paid up front at the start of the machine's service life and the dealership takes care of the maintenance. Bennet's firm has written some contracts that cover everything but fuel, but most contracts are not that comprehensive. The company does expect this program to expand in the future and to be a major source of revenue.

Similarly, Jung believes that dealerships will offer more ''total cost guarantees'' for the purchased equipment. This program will cover all repairs and maintenance, with the exception of wear parts, for 10,000 h of machine life.

Customer service will continue to improve with expanded maintenance service. Dealers will expand lube and maintenance services to allow small contractors to better maintain their equipment. Customers will be able to reduce or eliminate their mechanical support staff without sacrificing machine availability.

Power Plant Change

Component replacement is another change that Bennet sees on the horizon. Rebuilding will become less economical, and component exchange will be standard practice. Even engines will become a ''throw-away'' item, designed to last for a certain number of hours and then be scrapped, at which point a new engine will be installed in the unit.

Bennet feels that engine technology may change the most. Lightweight ceramic diesel engines may soon be available that will become quieter and more fuel-efficient. In an effort to maximize power and fuel efficiency, all diesels will be turbocharged.

Information Processing for Management

Jung thinks that technology improvements will continue to evolve. GPS tracking of equipment will allow the contractor to keep track of the location and hour meter reading of every unit. At some point even machine operating condition will be available in real time for all users.

Monnot also views advancements in the physical tracking of equipment as important. GPS satellites will track and transmit machine location, hour meter reading, and vital operating conditions such as engine temperature and oil pressure. The equipment manager will be able tell at all times where the machines are located and if they are being used. Machines that appear to have left their assigned project can be tracked even if stolen. Machines that indicate low oil pressure or overheating could trigger the dispatch of a service technician to check the problem before the operator or foreman even knows there is a problem.

Monnot says, ''where the contractor will see the most changes in equipment will be in fleet management.'' Costs for the equipment will be more closely monitored and improved equipment rates generated for bidding purposes. A mismanaged equipment fleet has the potential to lose a lot of money. Fortunately, tools are available to aid the tracking of everything put into a machine, how it is being operated, and what productivity it is achieving.

Service diagnostics and real-time communication of data for historical purposes will shorten unscheduled downtime and provide the estimators with equipment cost numbers they can trust. It will be easier for the equipment manager to know the rate of wear for almost any machine in the fleet and to schedule routine maintenance and component replacement.

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Fuel Consumption—Equipment Management Tool

Fuel and lubricants sometimes become a black hole on the project. Most companies still rely on the person adding fuel and oil in the field to write the added quantities on a log sheet. Technology is available to aid the tracking of fuel and lubricants. A computer barcode system can be used to identify the fueled machine. Computer records on the fuel or lubrication truck will track the type and quantity for each product dispensed to the machine. The information will then be sent to a computer in the office for processing and machine record updating.

Currently, correlating machine use hours (hour meter reading) and oil sampling are the most popular means by which companies determine service and component replacement intervals. Many in the industry feel that they are not good predictors in cases of extremely heavy or light duty machine use.

Equipment that works in extreme conditions may not receive adequate maintenance if the lubricants are changed at prescribed service meter intervals. Fuel consumption is one way to determine if the conditions are ''extreme.'' Machines engaged in heavy use run their engines at full load most of the time and therefore use more fuel per shift. Once a piece of equipment has used a certain quantity of fuel, it is time to change the oil. This tracking will also indicate if the operator is really working the machine to its full potential.

With equipment used in light duty applications it may be possible to extend the oil change interval. If a piece of equipment spends most of the day at idle, it will not use much fuel. However, the equipment manager may want to look at why the machine is not using fuel. Is the piece really necessary on the project? Corrective action may not be required, but fuel consumption can be another tool to indicate potential job-site productivity problems.

Machine components can also benefit from fuel-consumption tracking. Again, high fuel consumption indicates extreme service conditions, and the equipment manager may need to shorten the planned service life of engines, transmissions, and other components to prevent unplanned catastrophic failures. Using fuel consumption to guide service intervals can help a manager control the equipment fleet more efficiently. Fuel consumption becomes a self-compensating system to make sure the equipment is well maintained.

Crane Operation and Safety

There will be safety improvements on cranes. While computer-monitoring systems are not new, they will have added features: the new systems will record, for every pick, the weight of load, boom angle, and spool speed. These historical data could be helpful for bidding future projects or investigating crane accidents. The systems will be able to diagnose the electrical systems on the unit, allowing shorter repair time and improved machine availability.

Fleet management will become a predictable science for all constructors, not just the very large ones. Dealers will offer more guaranteed pricing and service for all customers, and the large equipment users will continue to refine data collection and planned preventative maintenance programs. Tracking all aspects of equipment use, productivity, efficiency, and rates of component wear will become easier and more affordable with the newer technologies.

The Future

James Douglas (1975) predicted that in the distant future it was conceivable that the discovery of new principles of subatomic structure would enable the excavation contractor to liquefy the cut material and pump it to the fill site. Twenty-seven plus years later it appears more probable that refinement and improvement will rule the future of construction equipment. Those predictions have not yet become reality, but they were presented as a vision of the distant future. The ideas Douglas offered are still valid, but without trying to move into the realm of the scientist as Douglas did, what are the equipment possibilities in the misty future? A vision is created here based on several specific tenets: (1) level of control improvements; (2) amplification of human energy; and (3) information processing. While parts of this vision may seem exotic fiction, it should be remembered that at least one manufacturer has already eliminated on-board operators from a fleet of experimental machines, and the idea of machines as mobile counterweights with a hydraulic powerplant is almost a reality today.

Rebuilding San Francisco in 2025

Let us follow the fictitious Heath Barger as he finishes his lunch and walks into the cellar that makes up his office on the afternoon of November 4, 2025. Heath works from his Oklahoma cellar as an independent equipment operator. Currently, he is working with Mega Inc., a large contractor that specializes in rebuilding urban infrastructure. Heath has worked several times in the past with Mega on projects in New York City and Chicago. Mega is a large multinational engineering/construction firm based in Singapore, which has become a world leader in the execution of difficult reconstruction projects. The current project is in San Francisco, which was recently devastated by a major earthquake.

Heath has a master of science degree in civil engineering from the University of Wisconsin, which he completed on-line from home. He is married with four children and likes to work on projects in time zones to the west of Oklahoma, as that means he can start work later in the day.

Heath greets his workspace as he enters the room. His ''computing power'' is provided by components that are built into the room itself, all of which communicate wirelessly. Three walls in the workspace act as large-scale display devices. Heath generally operates his equipment as he views images displayed on these surfaces. The wall displays work in conjunction with his glasses to give the images a 3D effect. When not interacting with his ''work walls,'' Heath reviews digital data that help him coordinate machine maintenance for his mobile power-source counterweight.

Heath, who is a Native American, used tribal grant money to lease his first mobile power-source counterweight from Globe Machines in Richardson, Tex. Globe owns most of the power source machines working on this project. Their technicians handle the actual machine maintenance but Heath and Globe's maintenance manager always confer before a component exchange. Shirley, the maintenance manager for Globe, has been working with Heath now for over 5 years.

From her workspace in Texas she sends information and instructions to her on-site team of technicians. Through speech, sketching, and hand gestures she simulates to the technicians how to actually install the component in the power source on the project. When she wishes, she calls upon component manufacturer support directly through linked computer systems. 'SunSpot Energy, the manufacturer, has been monitoring all of the machines' components by computer chips implanted in each component. SunSpot has a large historical database on any item of concern. This database will help Shirley and Heath decide on courses of action when there seems to be a problem.

Heath is a constructor of elevated formwork for bridge structures. His job is to design and construct the forming systems into

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which the concrete specialist located in Chicago will place their moldable mixture of refuse and epoxy. This project is being built following a virtual project design and analysis. This virtual design helped develop and refine the actual project; project estimates, schedules, and work methods and equipment were determined through the design process. Heath specializes in urban formwork construction, and he is one of the world's leading builders of formwork for bridges. His specially designed appliances, which are fitted on the leased power source, will build most of the formwork. With his appliances it is possible to erect the forms at night without generating more than 20 dBA of sound at 15.2 m (50 ft) from the work site; this is well below the San Francisco ordinance limiting nighttime noise to less than 55 dBA.

Heath's role in the project is to design and construct formwork for the designed structures. He does this in a way that, to a large extent, follows the way that office engineers and equipment operators used to work with the concrete forms in the old days. He will use materials that have already been "delivered" to the project. He must coordinate procurement of those resources with the Mega project manager in San Francisco.

Because unexpected events occur in the real world, he calls upon an extensive "project risks library" to simulate unexpected events, and his work strategy has flexibility for dealing with these risks. Once he has determined the exact sequence of work tasks that will lead to successful completion of the forming operation, he can be quite confident that the formwork will be in place as required by the project manager's master schedule.

As Heath carries out his construction operations, the images in his workspace present the actual construction site, and he performs his tasks by both voice and hand movement commands to his machine. The manufacturers of the formwork materials that are used on the project provide many of the control software components that he uses. Over the years, this software has become much more reliable at working together seamlessly.

Like any construction project, much of his work is highly interdependent with the work of others. Heath and other operators work collaboratively through their connected workspaces, and his machine interacts with theirs. The final constructed project is very much the result of their combined and coordinated efforts.

Conclusion

In the near future, few if any new and radical changes are seen on the horizon. Our existing equipment will become more versatile and efficient, with new attachments made possible by improved hydraulics, electronics, and powertrains.

The U.S. contractors will follow Europe and Japan in the move towards more rental and leasing of equipment rather than outright purchasing. The extent of the shift to rental and leasing will be guided by the U.S. tax code. The dealerships representing the manufacturers will need to shift their emphasis on rental to remain competitive in the equipment market.

Fleet management will become easier as technology makes it possible to collect and analyze data about productivity, efficiency, and maintenance. Problems can be identified and corrected before they become expensive catastrophes. Improper operating techniques that hurt production and possibly shorten machine life will be identified the day they occur and not weeks later. Components could be replaced closer to their failure point without risking costly core damage caused by waiting too long to change the component. Fuel consumption rates will determine maintenance intervals, thereby maximizing the balance between protecting the component life versus wasting money on too-frequent oil changes. The future is construction speed, quality, and lifetime project economics.

Since Douglas's (1975) attempt at predicting the distant future of construction equipment, there have been many advances in computer technology, or maybe more specifically chip technology. Additionally, guidance and positioning technology have all become practical tools. These advances in chips and guidance and positioning technology seem to offer a very different future for the application of mechanical devices to construction processes. The purpose of a machine is to perform a task that is beyond the capability of a human. The machines of the future will amplify human energy, as did those of the past, but control can come from any location.

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