LEAN PRODUCTIVITY ENHANCEMENTS AND WASTE ELIMINATION THROUGH EMERGING TECHNOLOGY

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Abstract

Lean methods focus on productivity enhancement and the elimination of waste through numerous principles, practices, and tools. Current lean principles, practices, and tools comprise a body of knowledge dating back centuries or further. This lean body of knowledge continues to evolve. An emerging theme within industry and the research literature has been to integrate technology into this body of knowledge to further improve productivity and eliminate waste. This paper surveys several different industries with example applications to document technological innovations being used to enhance productivity, eliminate waste and to contribute to the evolving lean body of knowledge.

Keywords: lean, technology, productivity, waste elimination, innovation

INTRODUCTION

The past three decades have witnessed the nature of lean as a systematic transformation process philosophy gain greater understanding. Lean is commonly defined and understood as a systematic philosophy for achieving productivity enhancements through waste elimination (Bhasin and Burcher, 2006). Benefits achieved through applications of the lean principles, practices, and tools are well documented. Often cited benefits attributed to lean applications are lower costs, higher quality, faster order response times, and enhanced transformation process flexibility (Ohno, 1988; Krafcik, 1988; MacDuffie, 1995; Pil and MacDuffie, 1996; Detty and Yingling, 2000; Shah and Ward, 2003; Melton, 2005; Singh, 2010; Fliedner, 2011).

The true understanding of lean's originations has been somewhat distorted by some suggesting that the roots of lean emanated from individuals (e.g., Toyoda, Ohno, Shingo, Imai, and others) within Toyota in the 1950's. Rather, lean represents an evolving body of knowledge dedicated to achieving productivity enhancements through waste elimination.

The true roots of the lean body of knowledge go back centuries. Individuals at Toyota acknowledged contributions to the lean body of knowledge by numerous predecessors. For example, the Egyptians used an assembly line (flow) practice and divided labor to enhance productivity and speed in the building of the pyramids (Dunham, 1956). The field of ergonomics contributes important lean practices as well. The foundation of ergonomics appears to have emerged in ancient Greece. Evidence indicates that the Hellenic civilization in the 5th century B.C. used ergonomic principles in the design of their tools, jobs, and workplaces (Marmaras, Poulakakis, and Papakostopoulos, 1999). It is estimated that as early as 1104, the Arsenal of Venice utilized a vertically integrated flow process consisting of dedicated work stations to assemble standardized parts into galley ships. This practice of a vertically integrated flow approach combined with standardized parts enhanced ship assembly productivity.

Other contributors prior to the contributions at Toyota include the introduction of interchangeable parts in the U.S. in approximately 1798 by Eli Whitney. Industrial engineers such as Frederick Taylor and the Gilbreths contributed practices such as standardized work, time and motion studies, and process charting during the scientific management era of the late 1890’s and early 1900’s. Starting in about 1910 through the 1920’s Henry Ford extended earlier practices by marrying interchangeable parts with standard work and moving conveyance as well as incorporating vertical integration and behavioral concepts such as worker motivation in order to design a more comprehensive lean system.

The contributions emanating from Toyota in the 1950’s, often referred to as the Toyota Production System (TPS), built upon earlier contributions and focused on waste elimination. Three wastes are typically identified; often referred to as overburden (muri), variation (mura), and waste (muda). Since the work by many at Toyota, numerous additional contributions may be cited. To put it simply, it must be acknowledged that lean is a philosophy of continuous improvement conducted in a systematic manner and dedicated to productivity improvements and waste elimination. Fliedner (2011) recognizes that as a system, lean is comprised of four integral components: leadership, organizational culture, and teamwork, as well as the practices and tools identified by many predecessors.

Interestingly, the nature of lean as a systematic philosophy for achieving productivity enhancements through waste elimination is quite broad and somewhat vague. For example, one can eliminate waste in a number of ways, including eliminating avoidable non-value adding activities, reducing unavoidable non-value adding activities, sharing information in a more timely and accurate manner, using more efficient resources, etc.

An emerging theme of lean rests on technological change as a means for achieving significant advancement of productivity enhancement and waste elimination objectives. Increasing anecdotal evidence is emerging which documents the ability of technology to enable productivity enhancement and waste elimination. Technological applications are impacting every industry, including agriculture, automotive, construction, entertainment, healthcare, and manufacturing to name a few. The purpose of this manuscript is to recognize and document examples as well as available beneficial evidence of the importance of these technological contributions. Technological applications are enabling and will continue to provide the future of lean achievements.

LEAN TECHNOLOGY CAPABILITIES

Productivity enhancements enabled by technology may be best explained in part to four laws. Chronologically, they are Moore's Law, Nielsen's Law, Butters' Law, and Kryder's Law. Moore's Law, offered in 1965, observed that the number of transistors in a dense integrated circuit doubles approximately every 18 months dramatically enhancing the effect of digital electronics in nearly every segment of the world economy (Moore, 1965). The capabilities of many digital electronic devices we take for granted these days are strongly linked to Moore's Law. Nielsen's Law, observed in 1998, states that the high–end users' internet connection speed (bandwidth), and therefore the ability to rapidly retrieve or exchange information, doubles approximately every 21 months (Nielsen, 1998). While Moore's Law observes that transistors double in speed roughly every 18 months, Butters' Law observed that the amount of data coming out of an optical fiber is doubling approximately every nine months, further enhancing the speed of information exchange over the internet (Tehrani, 2000). Kryder's Law observed that memory storage density or capacity (magnetic disk areal storage density at the time) is increasing very quickly, faster than Moore's Law at times (Walter, 2005). Taken together, these four laws directly contribute to the capabilities of emerging technology and therefore the productivity enhancements and waste elimination that will be achieved in coming years. These capabilities are embedded in the emerging technologies impacting every industry. Examples of these technologies as well as cited benefits for industries including agriculture, automotive, construction, entertainment, healthcare, and manufacturing as discussed below.

Agriculture

Technology is promoting lower costs, higher quality and faster order response times in numerous agricultural applications. Technology has greatly enhanced agricultural practices over the past decade and with the continuing trend for large farms and less labor per acre, it will continue to do so going forward. One current example is real time kinematic (RTK) vehicle auto steering capability. RTK provides hands-free steering accuracy measured to the inch for a variety of tasks including listing/bedding up, row crop planting, strip-tilling, ridge-tilling, post emergence spraying, banding fertilizer, side-dressing, and cultivating. This technology provides benefits of repeatability of these tasks from day-to-day or even year-to-year. It allows one to establish rows in the same spot for several years promoting controlled traffic systems, drip irrigation or any other use where one need to be able to come back to the exact same spot in the field. Benefits cited include significantly reduced driver fatigue which is best understood after one drives a tractor for several consecutive hours. It offers cost savings over older technology that can approach $50 per acre through reduced overlap on tillage passes. On a farm of 10,000 acres, that adds up to $500,000 annually (Anonymous, 2015b).

A second example is drone technology (unmanned aerial vehicle or UAV) which is making its appearance in many industries including real estate, military, distribution, search and rescue, and agricultural applications (Anonymous, 2015c). UAVs equipped with a multi-spectral camera can survey crops to detect water and nutrition issues, insect infestations, and fungal infections. UAV technology is being introduced to capture aerial field views for soil-moisture information for more efficient (location and duration) watering applications. UAVs equipped with appropriate camera filters and ground positioning technology (GPS) can detect nutrient deficiencies by providing an aerial field view. Overlaying this field view on a soil map can lead to the diagnosis of nutrient deficiencies (e.g., nitrogen or phosphorous) based upon crop coloration. The GPS can provide exact field coordinates so that the appropriate treatment can be applied to the corresponding area. This application can be applied during the growing season promoting yields and avoiding losses. Historically, fertilizer applications are performed before or after the growing season.

UAV technology offers a significant improvement relative to the more common uses of doing it on foot or more expensive and time consuming airplanes. Human sampling on foot or underground sensors lead to less reliable information as sampled areas may not be representative of an entire field. UAV information can lead to more efficient fertilizer and water applications which is particularly appealing for large scale farms. UAV size, cost, and capabilities promote significant efficiencies making UAVs useful for a wide range of jobs. One estimate suggests farmers can save $10 to $30 an acre in fertilizer and in related costs by examining the progress of crops while they are still in the ground (Ramstad, 2014).

Automotive

Technology has been applied in the automotive industry for decades and it will continue to be a leading innovator and adopter of technology to come. More than 30,000 people died on U. S. roadways in 2014 according to the National Highway Traffic Safety Administration (NHTSA). NHTSA estimates traffic crashes cost the economy $299.5 billion annually and that approximately 90% of crashes can be attributed to human error. Furthermore, it is estimated that Americans waste about 3 billion gallons of fuel annually due to congestion (Anonymous, 2015a). These statistics suggest most will agree that safety and traffic congestion are significant issues facing automotive transportation.

One example of emerging technology in the automotive industry is being pursued by Denso, a large, international supplier of advanced technology, systems and components. The particular innovation is referred to as vehicle-to-vehicle and vehicle-to-infrastructure (V2X) technology. This technology allows vehicles to wirelessly exchange data with other equipped vehicles and roadway infrastructure (Anonymous, 2015a).

The Federal Communications Commission will allow the use of the 5.850-5.925 GHz band of radio frequency spectrum which the U. S. Department of Transportation (DOT) has set aside for road safety and traffic management. This portion of the radio frequency spectrum is to be used for a variety of dedicated short range communications (DSRC) uses, including traffic light control, traffic monitoring, travelers' alerts, automatic toll collection, traffic congestion detection, emergency vehicle signal preemption of traffic lights, and electronic inspection of moving trucks. DSRC technology data transmissions will use both onboard and nearby roadside transmission facilities. This is part of the national program of the U. S. DOT's Intelligent Transportation System.

Denso's DSRC system utilizes a two-way, short-range wireless communications technology. The more vehicles equipped with DSRC devices, the more effective the technology. When all cars have V2X, it creates a 360-degree situational awareness for each vehicle's surroundings. The embedded computing device on each car can use information about nearby vehicles to calculate current and future positions. This can help predict hazardous situations and alert drivers of precautions to avoid crashes.

V2X technology can be used to give right-of-way to emergency vehicles. When an emergency vehicle is approaching, the technology will change the traffic light at intersections and alert surrounding vehicles to switch lanes.V2X can also support enhanced mobility and environmental responsibility. DSRC technology can provide red or green light timing advisories to in-vehicle systems to compute appropriate speeds for optimized fuel efficiency, reduced vehicle emissions, traffic flow to reduce congestion, and time-saving driving habits. This information-sharing technology has the potential to improve driving quality and save lives, reduce costs, and promote cleaner environment.

Architecture, Construction, and Engineering

Late in 2011, construction on the 736 foot tall, 52-story Leadenhall Building in downtown London, England began. This project required many innovative architectural, construction, and engineering (ACE) solutions and significant coordinated cooperation among its numerous stakeholders in order to meet its multiple tight constraints. First, it had an expected construction timetable of two years, which is extraordinarily short for a super skyscraper. Second, there was virtually no logistics support space at the construction location. The storage space for materials was approximately 10 feet wider than the building footprint because it was located immediately downtown in London. With no logistics support space, components and modules arrived during the late evening for consumption during that evening as storage was not possible. This necessitated exacting component and module specifications to ensure each could be slotted exactly into position upon arrival. Third, fabrication was not performed on site. On-site fabrication would have allowed for custom fitting. However, the limited logistic space prevented on-site material and equipment storage. Even a large scale work force was not feasible given space constraints. The building components and modules were fabricated off-site at several locations, some of which were hundreds of miles away such as in Worksop, England and Enniskillen, Northern Ireland. Some modules were nearly completely outfitted off site with pipe work, electrics, plumbing, and floor plates and transported to the site again necessitating exacting component specifications in the off-site fabrication as on-site fabrication and storage was not possible. Fourth, the building had to adhere to rigorous downtown London planning regulations.

One example of the lean technology contribution in this ACE example is the three dimensional (3D) modeling (simulation) that was employed. A comprehensive 3D model was created to facilitate construction objectives. This 3D model afforded several waste-eliminating benefits. First, it enabled multiple stakeholders to practice the assembly in a virtual manner. The participants ran the complete simulation to build the Leadenhall Building 37 times. The 3D practice afforded just-in-time delivery of the materials preventing any violation of the logistics support constraint. These practice sessions ensured that the advance time slot for every delivery for each crane lift, beam, bolt, and cable fix met the rigorous construction timetable. It was estimated the project would have been impossible to coordinate delivery and component installations with conventional 2D blueprints. Second, the 3D virtual simulation enabled participants to engage in the simulated practice regardless of their physical location. Third, the asymmetric building shape led to the foundations settling differently. The 3D model enabled engineers to plan for settling differences and to provide an innovative solution of jacks and removable steel-plate shims to adjust the lean of the building.

In the end, nearly 40,000 components were assembled on site in under two years which represents a European construction record for a building of this size. The 3D digital engineering model better enabled project feasibility as well as affording the project stakeholders the ability to eliminate tremendous wastes typical of a super skyscraper.

Rapid Prototyping

By itself, engineering supports numerous industries beyond architecture and construction. Technology is having a noteworthy impact in numerous engineering and manufacturing applications outside of ACE. Rapid prototyping

(RP) is one example. RP is a group of related tools used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data quicker, at lower cost, with tremendous ability to offer customization (flexibility), to exacting specifications (quality), and in small batch sizes thereby eliminating the need for large volumes to achieve economies of scale.

RP has been applied in numerous applications including design visualization (e.g., in the 3D architectural model of the Leadenhall building noted above), CAD prototyping, metal casting (e.g., General Electric's use of RP jet engine fabrication discussed below), education, geospatial analysis, healthcare (e.g., fabrication of implants and prosthetic devices), entertainment (e.g., video games), and retail (e.g., eyeglass frames and shoe fabrication).

RP fabrication is typically performed using 3D printing or "additive layer manufacturing" technology. Historical manufacturing processes have employed subtractive methods such as milling, planning, and drilling. The RP process utilizes computer generated 3D information that is exported to a 3D printer, which then builds up a scale model layer by layer. The scale model is effectively materialized. One of the advantages of RP is that it allows a testable model to be quickly produced to determine proof of concept for a particular application. Generating a model quickly eliminates waste by determining applicability of an idea or part for its intended use. Additive layer manufacturing greatly reduces the waste incurred in subtractive methods by ensuring only material needed is used to fabricate the part.

General Electric (GE) notes that it has developed a fuel nozzle using RP for the Leading Edge Aviation Propulsion (LEAP) jet engine. GE utilizes a direct metal laser melting process enabling groundbreaking customization of multiple LEAP components. Essentially, parts are created directly from a CAD file using layers of fine metal powder and an electron beam or laser. GE claims that this part is up to 25 percent lighter promoting fuel efficiency, five times more durable than its predecessor, and it is more complex than its counterparts by combining into one part what was assembled from as many as eighteen parts in a multistep manufacturing process in the past thereby reducing system throughput time (General Electric, 2013).

An example taken from the construction industry uses concrete printing, which employs highly controlled cement based mortar extrusion process which is precisely positioned according to computer data. The additive process has the ability to create custom-shaped construction components (e.g., a wall). The process has the potential to create architecture that is more unique in form. Material components do not have to be made from solid material, and so can use resources more efficiently than traditional techniques. For instance, allowances can be made for embedded conduits in components to directly accommodate utilities (e.g., electrical, plumbing, or telecommunications).

Additional reported benefits of RP include increasing effective communications (e.g., concurrent engineering) and reducing engineering design, development time, and error costs. RP enhances communications in part through its visualization capability. People tend to be visual learners. The extent to which representatives from functional disciplines such as engineering, manufacturing, marketing, and purchasing can see a rendered virtual model or hold a physical, 3D representation enhances their understanding of final outcomes.

RP has been reported to have the ability to reduce engineering and development time as well as decreasing error costs. RP allows modifications or corrections to be made early in the process when changes are less expensive to make. For instance, scale models can be used for testing (e.g., wind tunnel testing) as well as for tooling and casting purposes. The impact of technology in these additional engineering applications is enabling the benefits of lower costs, higher quality, faster orders response times, and enhanced transformation process flexibility.

Entertainment

Disney Entertainment has recently introduced experimental wearable technology (bracelets) that electronically link visitors to an encrypted big data collection and analysis system. The data collected allows for analysis to promote efficiencies through ride staffing adjustments, restaurant menus, and ride queue information. The wearable technology can also serve as admission tickets, hotel keys, and credit or debit cards. Disney reports that this system helped it accommodate 3,000 additional guests during the Christmas holiday season by reducing theme park congestion which it states results in an enhanced visitor experience (Palmeri, 2014).

Healthcare

Technology is providing numerous health-related improvement opportunities in electronic healthcare. Two examples are attributable to the evolution of Multidetector Computed Tomography and Magnetic Resonance Angiography technologies for medical imaging. These technologies have led to less invasive and more informative radiological diagnosis. These technologies promote enhanced higher image quality and therefore interpretive accuracy (Kido, Kurata, Higashino, Sugawara, Okayama, et al., 2007; Meaney and Goyen, 2007).

Telecommunication capabilities along with increased internet bandwidth are promoting tremendous growth in another field of medicine, clinical telemedicine. One estimate of the growth rate for this medical field will be 18.5 percent annually at least until 2018 (Hall, 2013). A 2012 report from Massachusetts-based market research firm BCC Research estimates the global telemedicine market will grow from approximately $11.6 billion annually in 2011 to about $27.3 billion annually by 2016 which represents 135 percent growth over 5 years.

The growth rate of telemedicine is attributable to numerous benefits, including improving access, especially for home-bound people or those located in rural or remote locations, reducing the transmission of infectious diseases or parasites, better resource capacity utilization, shortening report turnaround times, as well as improving the satisfaction of both patients and healthcare providers (Bruce, 2010; Johnson, 2014; Spring, 2011). It goes without question that the drivers for the growth of this healthcare technology are largely overall cost savings, speed, and flexibility; all as a result of productivity enhancements and waste reductions.

There are many specific examples of telemedicine. Some are conducted using asynchronous communications capabilities such as the transmission of electronic medical records and radiological reports and images. Some are conducted using synchronous communication capabilities over phone or mobile devices such as online video consultations. Other forms rely upon various alternative technological devices such as teleconferencing, robotic surgery, or remote monitoring.

There have been disadvantages cited to telemedicine as well. Included among these disadvantages are the costs of telecommunications equipment and medical personnel training, concerns over the protection of patient health information, potential for increased errors, possible decreased personal interactions which may be more revealing than remote interactions, and others. Needless to say, these exist in the presence or absence of the technology.

Manufacturing, Warehousing, and Supply Chains

New technologies are continually being applied and enhancing lean capabilities in numerous ways in order to drive continuous improvement efforts in manufacturing, warehousing, and supply chains. Technological innovation is enabling timely and accurate information exchanges among multiple locations in distributed supply chain networks (Francis, 2008). Examples of these innovative development investments include wireless network capabilities (e.g., Bluetooth and wireless local area networks), auto identification technologies (e.g., radio frequency identification or RFID and bar coding), laser guided vehicle technology, pallet shuttles, and cloud-based computing applications. These innovations offer numerous real-time supply chain benefits, including traceability, stock visibility, enhanced data accuracy and timeliness, reduced shrinkage, and real-time system monitoring (Lim, Bahr, and Leung, 2013; Ferrara, Gebennini, and Grassi, 2014; Zhang, Zhang, Du, Wang, Ail, and et al., 2014; and Guo, Ngai, Yang, and Liang, 2015).

RFID technology enhances information visibility and traceability (Delen, Hardgrave, and Sharda, 2007). RFID technology has become economically feasible for most firms. RFID system element (e.g., tags, readers, and antennae) costs vary depending upon the application. RFID tag pricing is variable and based upon many factors such as purchase volumes, tag memory bits, tag packaging (e.g., whether it is encased in plastic or embedded in a label), its active or passive nature, and wave frequency. Passive RFID tags maybe cost as little as 7 to 15 cents. Active tags may range from $20 to in excess of $100 as one chooses potential features such as protective housing, battery life, or sensors (e.g., temperature, humidity, etc.). Similarly, RFID reader cost is variable and based upon many factors, including active or passive nature and high or low frequency. Reader costs largely begin at $100 and go upwards.

One important feature regarding RFID applications is reading range. Low wave frequency (LF) readers and tags have a shorter reading range (often less than 3 feet) and slower data transfer rate. Although LF systems may only read short distances, shorter range capability does offer the advantage of reducing cross talk occurrences, or the reading of an intended tag at nearby upstream or downstream work stations instead of the intended target tag.

One example pilot implementation for a multiechelon clothing manufacturer integrated LF RFID and cloud technologies within an intelligent decision support system architecture for the monitoring and capture of real-time work station production information (Guo et al., 2015). This information was used to assist the generation of optimal production schedules in a distributed manufacturing environment. Prior to the implementation, manual recordings were used to collect production information. This resulted in a significant time to read and analyze what were considered outdated and unreliable daily summary reports. Three reported benefits of the pilot implementation were observed. First, a 25 percent increase in production efficiency was achieved. This was attributed to greater visibility and transparency of production operations as well as the improved production scheduling effectiveness. Second, a 12 percent reduction in production waste was achieved. The enhanced production transparency reduced overproduction, defects, and unnecessary inventories. Third, an 8 percent reduction in labor and system costs was achieved largely through the elimination of need to input job tickets, the need for fewer computer servers due to the cloud-based approach, and lower installation and maintenance costs. Intangible benefits of more timely production reports, more effective production scheduling performance, and faster throughput times were also observed.

SUMMARY

Numerous alternative technologies are being applied in virtually all industries today in order to achieve lean benefits of enhanced productivity and waste elimination. It is not possible to identify all of these technologies in this manuscript. Rather, the intention is to survey multiple examples and document evidence of the productivity enhancements and waste elimination that is possible

TABLE 1
Example Technologies that Enhance Productivity and Waste Elimination

Example Technologies	Communication Technology Platform	Example System Choices*
Real time kinematic (RTK)	Radio frequency spectrum and satellite-based positioning systems	UHF radio band and global navigation satellite system (e.g., GPS, GLONASS, Galileo, BeiDou)
Drone technology	Radio frequency spectrum and satellite-based positioning systems; Inertial Navigation Systems	VHF, UHF, and SHF radio bands and global navigation satellite systems
Vehicle-to-vehicle and vehicle-to-infrastructure (V2X)	Radio frequency spectrum	SHF radio band
Three dimensional (3D) modeling	Various 3D computer graphic vendors	Solid and shell modeling representations
Rapid prototyping (RP)	Various equipment vendors	Computer numerically controlled (CNC) routers; laser cutters; 3D printers
Wi-fi	Radio frequency spectrum	UHF and SHF
Asynchronous communications	Internet based	ASCII
Phone and cellular mobile devices	Code division multiple access (CDMA)	UHF radio band
Radio frequency identification (RFID)	Radio frequency spectrum	Ranging from LF for short range, low speed transmissions to SHF for long range, fast speed transmissions
Bluetooth	Radio frequency spectrum	UHF radio band

*Radio Frequency Spectrum Bands:
LF = low frequency; 30-300 kHz
MF = medium frequency; 300-3000 kHz
HF = high frequency; 3-30 MHz
VHF = very high frequency; 30-300 MHz

UHF = ultra high frequency; 300-3000 MHz
SHF = super high frequency; 3-30 GHz
EHF = extremely high frequency; 30-300 GHz

through the application of various technologies. A summary of these technologies surveyed is shown in Table 1.

Many of the technologies noted in Table 1 are radio-based spectrum technologies. Other technologies are computer-based software, internet-based, or satellite-based used in conjunction with radio-based spectrum. Many of these technologies are used in numerous industries as well. For instance, beyond the agricultural applications of drone technology, numerous additional UAV applications may be noted. Several of these UAV examples include military applications, movie-making by the film industry, search and rescue operations and crowd monitoring by governmental agencies, power line and pipeline inspection by utility companies, as well as delivery services by various retail firms to name just a few.

It should be evident from the beneficial data cited that the application of various technologies in the commercial examples noted are but small sample of the lean enabling advantages offered by innovative technologies. The benefits cited demonstrate clear productivity enhancements and waste reductions. Technology applications might start out within a small, localized portion of a process or they might enable global supply chain trading partners to collaborate while being located on different continents. The application scale of technology being adopted is quite varied. Regardless of the application scale, as evidenced in the examples cited in this manuscript, technology is enabling lean benefits including lower costs, faster response times, higher quality, and greater flexibility all through enhanced productivity and reduced waste. Technology will continue to be integrated into the lean body of knowledge to drive further productivity improvements and waste elimination. Technology represents the frontier of lean.

REFERENCES

Anonymous. 2015a. All About V2X: Talking Car Technology. Denso Dynamics (http://www.densodynamics.com/all-about-v2x-talking-car-technology/; accessed February 24, 2015).

Anonymous. 2015b. Agribusiness: New RTK System Putting Tractor Guidance on the Curve. Delta Farm Press (http://deltafarmpress.com/agribusiness-new-rtk-system-putting-tractor-guidance-curve; accessed February 23, 2015).

Anonymous. 2015c. Research Applications of Unmanned Aerial Vehicles. Phys.org (http://phys.org/news/2015-01-applications-unmanned-aerial-vehicles.html; accessed February 23, 2015).

Bhasin, S. and Burcher, P. 2006. Lean Viewed as a Philosophy. *Journal of Manufacturing Technology Management* (17:1/2), 56-72.

Bruce, C. 2010. Telemedicine: Growth and Impact. Healthcare Review (http://www.healthcarereview.com/2010/09/telemedicine-growth-and-impact/; accessed March 2, 2015).

Collins, J. 2001. Good to Great. Harper Collins Publishers, New York, NY.

Delen, D., Hardgrave, B.C., and Sharda, R. 2007. RFID for Better Supply-Chain Management Through Enhanced Information Visibility. Production and Operations Management (16:5), 613-624.

Detty, R.B. and Yingling, J.C. 2000. Quantifying Benefits of Conversion to Lean Manufacturing with Discrete Event Simulation: A Case Study. *International Journal of Production Research* (38:2), 429-445.

Dunham, D. 1956. Building an Egyptian Pyramid. Archaeology (9:3), 159-165.

Ferrara, A., Gebennini, E., and Grassi, A. 2014. Fleet Sizing of Laser Guided Vehicles and Pallet Shuttles in Automated Warehouses. *International Journal of Production Economics* (157), 7-14.

Fliedner, G. 2011. Leading and Managing the Lean Management Process, Business Expert Press, New York, N.Y.

Francis, V. 2008. Supply Chain Visibility: Lost in Translation? *Supply Chain Management: An International Journal* (13:3), 180-184.

General Electric. 2013. Additive Manufacturing: The Next Industrial Revolution (http://www.geaviation.com/company/additive-manufacturing.html; accessed March 4, 2015).

Guo, Z.X., Ngai, E.W.T., Yang, C., and Liang, X. 2015. An RFID-based Intelligent Decision Support System Architecture for Production Monitoring and Scheduling in a Distributed Manufacturing Environment. *International Journal of Production Economics* (159), 16-28.

Hall, S.D. 2013. Global telemedicine market forecast: 18.5% growth rate through 2018. FierceHealthIT (http://www.fiercehealthit.com/story/global-telemedicine-market-forcast-185-percent-growth-rate-through-2018/2013-12-16; accessed February 24, 2015).

Johnson, S.R. 2014. RAND Study Cites Telemedicine Benefits: Lowers Costs, Expands Access. Modern Healthcare (http://www.modernhealthcare.com/article/20140203/NEWS/302039952; accessed March 2, 2015).

Kido, T., Kurata, A., Higashino, H., Sugawara, Y., Okayama, H., Higaki, J., Anno, H., Katada, K., Mori, S., Tanada, S., Endo, M., and Mochizuki, T. 2007. Cardiac Imaging Using 256-Detector Row Four-Dimensional CT: Preliminary Clinical Report. Radiation Medicine (25:1), 38-44.

King, A. and Lenox, M. 2001. Lean and Green? An Empirical Examination of the Relationship Between Lean Production and Environmental Performance. Production and Operations Management (10:3), 244-256.

Krafcik, J.F. 1988. Triumph of the Lean Production System. Sloan Management Review (30:1), 41-52.

Lim, M.K., Bahr, W., and Leung, S.C.H. 2013. RFID in the Warehouse: A Literature Analysis (1995-2010) of its Applications, Benefits, Challenges, and Future Trends. *International Journal of Production Economics* (145), 409-430.

MacDuffie, J.P. 1995. Human Resource Bundles and Manufacturing Performance: Organizational Logic and Flexible Production Systems in the World Auto Industry. Industrial and Labor Relations Review (48:2), 199-221.

Marmaras, N., Poulakakis, G., and Papakostopoulos, V. 1999. Ergonomic Design in Ancient Greece. Applied Ergonomics (30:4), 361-368.

Meaney J.F. and Goyen, M. 2007. Recent Advances in Contrast-Enhanced Magnetic Resonance Angiography. European Radiology (17:2), B2-B6.

Melton, T. 2005. The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries. Chemical Engineering Research and Design (83:6), 662-673.

Moore, G.E. 1965. Cramming More Components onto Integrated Circuits. Electronics, 114-117.

Nielsen, J. 1998. Nielsen's Law of Internet Bandwidth. Alertbox (http://www.nngroup.com/articles/law-of-bandwidth/; accessed February 23, 2015).

Ohno, T. 1988. The Toyota Production System: Beyond Large-Scale Production, Productivity Press, Portland.

Palmeri, C. 2014. Disney Bets Big on Visitor-Tracking Technology. Bloomberg Businessweek (http://www.bloomberg.com/bw/articles/2014-03-07/disney-bets-1-billion-on-technology-to-track-theme-park-visitors; accessed February 23, 2015).

Pil, F.K. and MacDuffie, J.P. 1996. The Adoption of High-Involvement Work Practices. Industrial Relations (35:3), 423-455.

Ramstad, E. 2014. At Minnesota's Farmfest, Drones and Data Fly onto the Agenda. Phys.org (http://phys.org/news/2014-08-minnesota-farmfest-drones-agenda.html#inlRlv; accessed February 23, 2015).

Robinson, G. 2000. Speeding Net traffic with Tiny Mirrors. Electronic Engineering Times, 30-31.

Shah, R. and Ward, P.T. 2003. Lean Manufacturing: Context, Practice Bundles, and Performance. *Journal of Operations Management* (21:2), 129-149.

Singh, B., Garg, S.K., Sharma, S.K., and Grewal, C. 2010. Lean Implementation and its Benefits to Production Industry. *International Journal of Lean Six Sigma* (1:2), 157-168.

Spring, M. 2011. Telemedicine: Advantages and Disadvantages. Healthguideinfo.com (http://www.healthguideinfo.com/health-informatics/p6499/; accessed March 2, 2015).

Tehrani, R. 2000. As We May Communicate. Tmcnet.com (http://www.tmcnet.com/articles/ comsol/0100/0100pubout.htm; accessed March 2, 2015).

Ter Maat, S. 2013. WellPoint Expands Telemedicine Opportunities for Doctors. Amednews.com (http://www.amednews.com/article/20130130/business/ 130139999/8/; accessed February 24, 2015).

Walter, C. 2005. Kryder's Law. Scientific American, 32-33.

Zhang, Y., Zhang, G., Du, W., Wang, J., Ali, E. and Sun, S. 2015. An Optimization Method for Shopfloor Material Handing Based on Real-Time and Multi-source Manufacturing Data. *International Journal of Production Economics* (165), 282-292.

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