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REVIEW ARTICLE

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Intelligent data analytics is here to change engineering management

Abstract A great deal of scientific research in the world aims at discovering the facts about the world so that we understand it better and find solutions to problems. Data enabling technology plays an important role in modern scientific discovery and technologic advancement. The importance of good information was long recognized by prominent leaders such as Sun Tzu and Napoleon. Factual data enables managers to measure, to understand their businesses, and to directly translate that knowledge into improved decision making and performance. This position paper argues that data analytics is ready to change engineering management in the following areas: 1) by making relevant historical data available to the manager at the time when it's needed; 2) by filtering out actionable intelligence from the ocean of data; and 3) by integrating useful data from multiple sources to support quantitative decision-making. Considering the unique need for engineering management, the paper proposes researchable topics in the two broad areas of data acquisition and data analytics. The purpose of the paper is to provoke discussion from peers and to encourage research activity.

Keywords engineering management, project management, big data, data analytics, planning, execution

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1 What is engineering management?

Engineering's grand challenges are to provide solutions that can sustain civilization's continuing advancement while still improving the quality of life (NAE, 2008). Engineers have been continuously developing new tools and technologies to drive the advancement of civilization, and to create applications of scientific principles to solve real world problems. On the other spectrum, management is to coordinate people and to allocate resources with the goal of achieving efficiency. Engineering management discipline is born of the need for developing solutions to complex engineering problems requiring the collaborative effort of a multi-disciplinary team and extensive resources. It is recognized as a specialized form of management that is concerned with the application of engineering principles to business practice[1]. Engineering management is at the intersection of engineering and business by bringing together the technological problem-solving skills of engineering and the organizational, administrative, and planning abilities of management. Its goal is to effectively manage complex engineering projects/processes, such as research and development (R&D) for new products and construction of infrastructural projects (Barnhart et al., 2007). An engineering manager (EM) oversees engineers, scientists, and technicians who design and develop machinery, products, and systems/facilities.

An EM's duties cover three categories: planning, execution, and controlling with the objective to achieve the project goals by optimizing the utilization of limited resources available to the project. In general terms, resources include people, money, equipment and tools, materials and time. Specifically, an EM's job is to plan and determine each player's role in the project and to allocate available resources in order to achieve the goals of the project.

1) Engineering management. https://en.wikipedia.org/wiki/Engineering_management, 2016-10-25

Planning is the process to run the project on paper/computer before it starts. It involves making decisions on what to do, when to do it, who will do it and how to do it. Execution is to execute and manage the actual implementation process by turning plans into reality. Control refers to decisions and actions in dealing with changes which occur at the execution stage with the objective to minimize their negative impact on the project (Hinze, 2012).

The common challenges for a successful EM include: 1) to create a good plan that can closely reflect how the project will be executed in the real world; 2) to effectively execute the plan by allocating available resources efficiently; and 3) to promptly detect changes, to quantify their impact, and to take necessary actions to ensure the project on the right track.

To overcome these challenges, an EM must be equipped with: 1) technical knowledge to fully understand and appreciate the given engineering problem, 2) extensive management skills to make timely decisions, 3) right information, and 4) relevant experience to the given problem. Education can address the first two requirements. The EM has to rely on other resources and experience to meet the latter two requirements.

A common mistake for many EMs is to underestimate or even misunderstand the complexity of a given engineering problem. Such a mistake can lead to impractical plans, and cause serious cost and/or time overruns at the execution stage. A conventional practice to address the potential problem is to place an experienced individual as an EM for an engineering project. Experience is expected to help the EM better understand the problem and find good solutions. How many people can replace a flat tire correctly in the first time? We learn from our own experience. That's the traditional belief. If a millennia gets a flat tire the first time, however, she/he will probably turn to her/his smart phone to GOOGLE for help and to watch a 2-minute video on YouTube "How to replace a flat tire?" Technology has enabled a shared economy/society. Millions of people have put their experience and skills online available to us at fingertips to compensate for the lack of personal experience. We may be surprised from time to time at home by witnessing or hearing that our teenage kids have solutions to seemingly complex problems. The smart phone gives them a platform, and the search engine gives them the bridge to cross any waters. Although experience is helpful, one person's experience is always limited, and may be biased or misleading sometimes. If one uses his one-time driving experience in downtown Chicago to plan his driving time for a job interview, good luck for being there on time. The author would like to argue that experience is commonly overrated in engineering management. We don't live in island anymore. Instead, we are all connected and live in the age of big data that has become an enabling agent to bring the right information including relevant knowledge and experience to empower us for improved decision-making and problem-solving.

2 Why big data and data analytics?

Sun Tzu's Art of War says "Know yourself and know your enemy. You win all battles." Napoleon Bonaparte attributed most of his military success to having the right information as he put it "War is ninety percent information." Data appears as numbers on paper, but can become intelligent information after being analyzed and can be turned into competitive advantages, such as high speed trading used by Wall Street (Aldridge, 2013).

Data provides us with the information to understand real world problems and to discover solutions.

Data enabling technology plays an important role in modern scientific discovery and technologic advancement. Huber telescope lets us see deeper into the dark sky. Global positioning system (GPS) allows us to locate exactly where a subject is. Missing information can lead to misunderstanding, mystery or even disaster. The disappearance of Malaysia Flight M370 was a mystery for years because its tracking system was turned off. Tens of millions of dollars have been spent to search and locate its wreckage.

Just two decades ago, Google didn't exist and there were no other information sources for general public access. Data was owned independently and no cross-referencing or searching was possible. Technological constraints didn't permit unlimited data to be centrally stored and managed. Access to data was inefficient, expensive and segregated. Library was the only place to find limited information piece by piece. Today, data centers are the biggest construction projects. The capacity to store data and means to access information through cloud computing have enabled the public to find out the world's facts just mouse clicks away, such as the location of every factory in the world, and specialties and insurance preferences of 1.8 million United States health care professionals (McAfee and Brynjolfsson, 2012). More and more data are collected, acquired and organized by numerous players at a faster speed. It is estimated digital data grows at 50 percent a year, or more than doubling every two years (Manyika et al., 2011). As digital sensing and internet technologies rapidly advance, countless digital sensors worldwide in locations, industrial equipment, automobiles, and shipping containers are recording and communicating their location, movement, vibration, temperature, humidity, and even chemical changes in real time (Davis et al., 2012). Such information enables a tourist to preview a vacation destination before boarding the airplane. It permits a global manufacturer to coordinate and optimize its manufacturing capacities at different plants around the world (Kang et al., 2016). Information is turned into added value to improve quality of life and productivity.

The author has seen the same family doctor for more than ten years. Recently, the doctor's office has made all laboratory test results since 2005 available to its patients on line. After analyzing the trends of the lab results of particular interest, such as cholesterol, high density lipoproteins (HDL), low density lipoproteins (LDL) and glucose, it allowed the author (not a medical professional) to fully understand his health conditions and what he should watch for and what he should/should not do.

Now let's imagine a little bit further, if we have continuously monitored our other health parameters, such as heartbeat, blood pressure, and weight for years, would we know our physical health much better even though we are not a medical doctor? Would an annual routine physical checkup at the doctor's office be different from now? Instead of checking the patient for any wrong conditions, the doctor could review the patient's health patterns and explain the test results concerning his/her health. By comparing these results to peer groups, the doctor can diagnose the patient more. Also imagine that our diet, exercise and sleep patterns are also collected continuously. Imagine one more time that we can integrate all the above information for an individual for a long period of time in which the person experienced different diet and exercise patterns. Would the doctor be in a better position to advise the patient of potential causes of her/his health problems and healthy living lifestyle? How far are we from the wishful thinking? Don't be surprised that the technology is here already. Smart phones can track the restaurants where we eat and credit card transactions and receipt details what we buy; smart watches can track our exercise and sleeping activities. After "I-pad" and "I-phone", "I-me" is not far away for individual's personal information to be fully integrated and centrally managed. Humanity has entered the new digital universe.

Big Data refers to the explosion in the quantity and quality of available and potentially relevant data, largely the result of recent and unprecedented advancements in data recording and storage technology (Manyika et al., 2011). Big Data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision-making, insight discovery and process optimization. McKinsey & Co. foresees that the society is 'on the cusp of a tremendous wave of innovation, productivity, and growth as well as new modes of competition and value capture — all driven by Big Data (Manyika et al., 2011). Eric Siegel, founder of Predictive Analytics World, estimates that on an average day we accumulate 2.5 quintillion bytes of data (Siegel, 2013). Data scientists are increasingly using data quantities in Peta and Zeta bytes. Businesses, governments and developmental organizations — all are foreseeing that Big Data is likely to create value in multiple (Lohr, 2012). Major technical challenges include capture, curation, storage, search, sharing, analysis, and visualization (Moorthy et al., 2015).

3 Big data in business management

Data is the basic building block for business management. As management guru, W. Edwards Deming, states: "In God we trust. All others must bring data." Clearly, data is needed to back up our ideas and decisions in order to effectively communicate with and convince others. "What gets measured, gets managed." This quote by the late management guru, Peter Drucker, explains it all. If a business cannot measure its activity, how can it manage or optimize its performance? Factual data is needed to describe the situation that the business faces. It enables managers to measure, and hence to understand their businesses, and to directly translate that knowledge into improved decision making and performance (McAfee and Brynjolfsson, 2012). As Moore (Moore, 2014) points out, "Without big data analytics, companies are blind and deaf, wandering out onto the Web like a deer on a freeway."

Data and analytics give a business valuable insights into what is and isn't working in order to maintain its competitiveness in the market place. When a company is battling for a competitive advantage in business, analytics data provides the intelligence for success. Research has repeatedly shown that data-driven decisions tend to be better and more effective. Companies with clear strategies to combine domain expertise with data intelligence will pull away from their rivals. Across industries, "big data" and analytics are helping businesses to become smarter, more productive, and better at making predictions. The impact of data abundance extends well beyond business. As McAfee and Brynjolfsson (2012) bluntly point out, business leaders will either embrace this fact or be replaced by others who do.

4 Data analytics for engineering management

Many engineering projects failed to achieve their original goals. Some were even abandoned after millions of dollars had been spent. Merrow (2011) examined 318 industrial mega-projects from upstream and downstream oil and gas, mining, pharmachem and power generation sectors, and found that only 35% of the 318 mega-projects could be considered as a success based on on-time and on-budget completion. Miller and Lessard (2000) reviewed 50 projects and found less than 50% meeting major objectives with nearly 20 percent of them being failures or even abandoned. Based on extensive reviews since the 1970s, Brookes (2014) summarized the top three causes of the failures as following: 1) incorrect scoping of the project at the early stage, 2) strategic misrepresentation of the project, and 3) lack of structured decision-making. Apparently, these causes are all closely related to quality data and its proper use in the decision-making process. The following sections briefly describes how data analytics may assist engineering management in the three phases of a project: planning, execution and control.

4.1 Project planning

The importance of a good plan cannot be over emphasized for the success of an engineering project. Poor planning has been attributed as one of the most important reasons for mega-project failures (Brookes, 2014). 73 percent owners felt that poor planning is a significant cause of cost overruns (Hinze, 2012). Developing a good plan for a complex engineering project requires the planner to have a good understanding of the project, to recognize its uniqueness and similarities with other projects, and to avoid big mistakes (e.g., missing or misrepresenting major components).

Imagine that when a planner is working on a plan for a given new project, she/he can virtually walk through the given project and similar previous projects. During the process, major similarities and dissimilarities between the new project and other projects could be called out to catch the planner's attention. Also imagine that after a draft plan is drawn up, an intelligent system can check the plan against the plans of similar projects, lessons learned, and requirements and constraints for the given project. This step would give the planner an opportunity to reconsider the given conditions and revise the plan as appropriate.

Currently, this essential function is provided by human experience inside the organization. Since each engineering project is always unique and an individual's experience is always limited, mis-scoping remains a major cause for poor project performance. Imagine that a broad range of engineering project data is accessible in different forms from the dashboard of the planner, would such relevant professional experience of others greatly help the planner to draw up a better plan and avoid errors?

We can learn a great lesson from computer-aided design (CAD). CAD is regarded as the greatest innovation in engineering design in the last fifty years (De los Reyes, 2006). It started as a computer drafting tool; gradually design standards, design intelligence, analytic tools, and vendors data are integrated into the system which allows a designer to draft, analyze, change and optimize system design in one environment. The embedded standards, codes, intelligence and other valuable features can check design errors instantly. Experienced structural engineers used to be the highest demanded profession among civil engineers. The advanced CAD technology supported by data analytics has changed the industry. It has led to more accurate designs, quicker design completions, improved organization and sharing of data, and higher productivity within the engineering office. A great deal of quality data exist for engineering projects, such as historical project data, best practices, lessons learned, and trades. Can someday such valuable assets of big data be embedded with project planning tools to support project planners like CAD has supported designers?

4.2 Project execution

The person who is responsible for running an engineering project is project manager (PM). PM may or may not be the planner who prepared the plan for the project. Project execution is to allocate available resources to move the project forward according to its plan. Given that multiple parties are always involved in a project, each party must know exactly the piece that her/his sub-team should make and all the pieces must match perfectly as illustrated in Fig. 1. However, it's not uncommon for a teamwork to end up in an unpleasant situation as shown in Fig. 2 in which each sub-team might seem doing the right thing until it's too late for them to recognize that they are not on the same page. A successful PM must perform three key management functions: 1) run daily operations and solve problems encountered in the field; 2) pre-plan and set the ground for things to occur as planned; and 3) incorporate changes that have occurred or will occur to update project plans and execution strategies.

Fig. 1 Ideal project coordination

In order to effectively perform the three functions, the PM must know what is going on with the project, understand the changes that have occurred and their potential impact to the project, and be prepared for possible changes that will likely occur. A large industrial project may have tens of thousands of workers in the field on a single day during its peak period and millions of things are happening at the same time. A lot of data is constantly generated. For example, a supplier may send in an email with an updated delivery schedule of an order—5 days after its original plan due to low stock. What's the impact on the project? Hopefully, somebody would catch it. Let's take a look of online shopping. After a customer makes an

Fig. 2 Unpleasant teamwork scenario

on-line purchase, the order status is constantly updated and the customer knows when the product will be delivered.

In the last few decades exciting new digital technologies have connected people through internet and communication networks. The internet of things (IoT) is the network of physical devices, vehicles, buildings and other items– embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data[1)]. Advanced manufacturing, or smart manufacturing technologies (aka Industry 4.0) is taking an advantage of these technologies to connect all production machines on a factory floor as a subnetwork which is linked with other sub-networks across multiple manufacturing sites and the entire supply network to integrate intelligence into an enterprise's manufacturing system (Davis et al., 2012; Kang et al., 2016). Integrated smart technologies can help manufacturers gain unprecedented real-time control of energy, productivity, and costs across factories and companies.

Let's envision a large industrial construction site in which each one of the ten thousand workers in the field is fully connected to the network; what they were doing and progress achieved are automatically sensed; materials installed are tracked; all equipment in the field is also fully connected to the same network and with working status and conditions monitored; all instantaneous events in the field are captured throughout the day; finally, imagine that all the above information is fully integrated in real time and can be presented in any form of a user's choice, would this full digital project management system give the PM a better tool to manage the project? Furthermore, proper analyses can be performed with all data collected; would the PM get a better picture of the project performance and make corresponding decisions as necessary for the project?

Imagine one scenario in which the PM is properly reminded with the fact that the same contractor whose work failed quality inspection two weeks ago will be back next week for another phase of the project. Would this reminder allow the PM to plan additional supervision of the contractor's work to avoid potential problems to repeat?

So many things are happening and so much data is available in an engineering project. How not to overload ourselves with all the information and lose our sight on things that require our attention? Imagine that the PM has a droid like Anakin's R2-D2 in the Star Wars movie. R2-D2 would be able to remember all the information and push the right information to the PM for decision or action when needed. Imagine that the PM is reminded at the beginning of the day that a likely safety incidence may occur based on an analysis of historical data: what was performed; who performed; and where it was performed. Would this reminder give the PM an opportunity to take precautions to avoid it?

All the above functions are currently achieved through the PM's experience, ability of being able to parse through all the data, and ability of being able to effectively communicate with other project participants. Data and analytics can help.

4.3 Project control

At the control stage, the PM is to make decisions in responding to changes that have occurred or may occur. Again, experience obtained from previous relevant projects plays an important role in today's engineering management. A successful PM must know how to deal with changes and revise the project plan constantly during the course of the project to assure its successful completion on time and within budget.

The conventional wisdom assumes that a person who

1) Internet of things (IoT). https://en.wikipedia.org/wiki/Internet_of_things, 2016-10-25

has relevant experience in dealing with similar situations would have developed the decision-making skills necessary for managing changes effectively. This is correct for many cases. However, everyone's experience has a limit; one's memory is imperfect; and everyone has blind spots. Data analytics can overcome these human constraints. Just imagine that when a chemical plant's nitrogen pipe is accidently hit and damaged by a delivery truck; and the PM has a comprehensive case database with detailed step-by-step procedures for various scenarios at her/his fingertips. Would this save the day for the PM regardless of her/his previous experience?

Data analytics is here to change engineering management practice. The companies that will have a competitive advantage in the marketplace will be the ones that will break away from the traditional approach of human intuition and expertise-based sense and respond mode of business operations to one in which the next generation of manufacturing and production and in-service efficiencies will be achieved by providing precise, contextual analysis at the point of impact, thereby adopting a real-time, fact-driven predict and act.

5 Potential research problems

Data-driven decision-making faces two challenges: data quality and intelligence discovery. It's widely recognized that "garbage in, garbage out" in management when low quality data is used for analysis. It's also known that data hardly presents itself in obvious patterns; instead, it's usually coded and may appear multi-dimensional or misleading. As Ronald Coase pointed out, "if you torture the data long enough, it will confess." In order to achieve data-driven and evidence-based decision-making, project management professionals must develop appropriate methods and tools to address the unique challenges we face, such as, data availability and sources, acquisition technologies, analytic methods, and visualization techniques. The proposed research topics are not intended to be complete or even comprehensive.

5.1 Data acquisition

5.1.1 Data sources

A project data is generated along its life cycle starting from initial feasibility study, to design and implementation, operation, until demolition (Rujirayanyong and Shi, 2006). It is collected and owned by many participants at varying levels of granularity. Maged Abdelsayed of Tardif, Murray & Assoc. (Quebec, Canada) estimated the amount of information for a typical project of US$10 million as following (Hendrickson and Au, 2008):

- Number of participants (companies): 420 (including all suppliers and sub-sub-contractors)
- Number of participants (individuals): 850
- Number of different types of documents generated: 50
- Number of pages of documents: 56,000
- Number of bankers' boxes to hold project documents: 25
- Number of 4-drawer filing cabinets: 6
- Number of 20-inch-diameter, 20-year-old, 50-feet-high trees used to generate this volume of paper: 6
- Equivalent number of Mega Bytes of electronic data to hold this volume of paper (scanned): 3000 MB

Many of the data, such as designs and cost estimates, are generated by professionals during the process and are proprietary. Proprietary data is closely guarded since it may affect a participant's competitive advantage. Some data may be shared among related project participants, such as the owner and the general contractor, and may be revised and collected by several participants. Moreover, some data is automatically collected and stored by its responsible owners. Some other data is public and may be made public to meet regulatory requirements, such as weather data, delays, worker injury data and environmental impact. Significant costs are associated with the generation, storage, transfer, retrieval and management of the data.

5.1.2 Researchable problems

How to make such fragmented data sources available for new projects without compromising any party's interest, privacy and intellectual property? Research is needed to address the following challenges:

- Duplicate data sources and data reliability. An engineering project is multi-faceted, multi-dimensional and dynamic. It's common to get different numbers for the same measurement from different participants or at different times in the project lifecycle. Data generation and collection are currently intended to serve the need of managing the current project. The context around the data, such as its generation, updating history, and ownership, is essential to reconcile conflicts with similar data from other sources and to make it searchable for future projects. One of the main reasons that experience is greatly valued (maybe overvalued sometimes) is that a human expert can filter through the data and discover relevant information. The contextual information will be useful in building intelligent data analytics.
- Automated data acquisition technologies. Data acquisition involves measuring real world physical conditions and converting the measurements into digital numeric values. Advancement in sensors and communication technologies in the last decade has enabled low cost automated data collection. Especially plug-and-play smart sensors and systems allow a quick configuration and deployment of an integrated data acquisition system at low

cost for users without much technical training on sensing technology. The research task is and should be domain-specific to determine what data is needed and system deployment strategy.

• Proprietary data. Proprietary data is data that an organization owns and controls for its own purposes. In a recent Accenture study (Davenport and Redman, 2015), 97% companies acknowledged that proprietary data is "very valuable or "quite valuable" in differentiating a company from its competitors. In the same survey, only 10% of respondents agree that their company's proprietary data is more useful than the competition's. Overall, companies analyze no more than 1% of their data, and convert even less to proprietary advantage. A lot of proprietary data is generated during a project lifecycle, such as estimates and productivity. Such data generation is expensive. Because the data generated is to meet the need of managing the current project, the total cost for data generation is then fully accounted to the current project as well. Given the big cost paid and other concerns, such data is only reused inside an organization or even just by a few individuals who were involved in the data generation in the organization. If data is indeed an "asset," it should be traded in the market. To enable a broad based data reuse for project management, proprietary project data must be acquired and managed by independent parties. It's extremely important that privacy and IP of the original data owner must be protected so that the data owner would not worry that its competitive edge would be compromised.

• Independent data service providers. In order to enable sharing or reuse of broad engineering project data including proprietary data and proper protection of original data owners at the same time, data must be traded to benefit its owners while certain contextual information must be removed so that the owner's identity and intellectual property are not revealed. An independent data service provider is better suited to fulfill the requirement. In the current market, a limited number of for-profit consulting firms or not-for-profit organizations have collected a number of historical projects and offered benchmarking assessment at a fee for a given project. Such project databases are far from comprehensive and need to be expanded, and more intelligent data analytics are needed.

5.2 Data analytics

Data analytics is to mine available data with the goal to discover useful information to support a decision-making process. Some researchable problems are as follows:

• Improved distributed crawling techniques and algorithms are needed for scrap data from multiple platforms.

• Data cleaning and filtering techniques. Each engineering project is unique. Finding relevant data and filtering our irrelevant data is the key to reach confident decisions.

• Natural language processing methods. Natural language is widely used in project management to describe certain conditions, such as disputes and daily reports. Such texts provide important information to explain many things beyond numbers.

• Multimedia data processing capabilities. In addition to numbers and texts, an engineering project contains drawings, pictures, and videos. Building information modeling (BIM) technologies make a large amount of project design data available and exchangeable with other systems. A series of digital pictures or video clips may have been captured during the execution of the project. Finding such information related to a given event or incident quickly can provide the project manager with reliable information for making better decisions.

• Data visualization. Tables, figures and drawings are traditionally used in engineering. It takes technical knowledge to read and understand them. Advanced visualization technologies including virtual reality can significantly improve representation and communication of engineering problems and their solutions. Despite major technological advancement in the last several years, powerful algorithms and supporting software tools remain crucial for future development.

• New or improved analytic techniques. Many techniques have been developed for data analytics. Researchers continue to develop new techniques and improve on the existing ones, particularly in response to the need to analyze new combinations of data and on intelligent computation or machine learning.

6 Conclusions

Big data and data analytics are changing our daily life and work. This position paper intends to present the author's point of view how the technology may change engineering management practice. The technology can make broader relevant project data available to the PM at the time when it's needed so as to expand the manager's experience. The technology can also help the PM filter out actionable intelligence from the ocean of data. By integrating all useful data from multiple sources, the PM shall make better decisions. It's widely recognized, however, data in engineering project is very fragmented with complex data structures and ownerships. A lot of the data is proprietary and closely guarded as business secret. Many challenges lie ahead in order to achieve broader data sharing and deep intelligent data analytics. More research is needed. New business opportunities may open up for independent data service providers.

References

Aldridge I (2013). High-Frequency Trading: A Practical Guide to Algorithmic Strategies and Trading Systems. 2nd ed. Hoboken: John

Wiley & Sons

Brookes J N (2014). Mankind and mega-projects. Frontiers of Engineering Management, 1(3): 241–245

Barnhart C, Daskin M S, Dietrich B, Kaplan E, Larson R. (2007). “Grand challenges in engineering.” INFORMS – Institute for Operations Research and the Management Sciences. https://www.informs.org/About-INFORMS/INFORMS-Comments-on-Grand-Challenges-in-Engineering, 2016-10-25

Davenport H T, Redman T (2015). Getting advantage from proprietary data. http://blogs.wsj.com/cio/2015/03/11/getting-advantage-from-proprietary-data/, 2016-10-25

Davis J, Edgar T, Porter J, Bernaden J, Sarli M (2012). Smart manufacturing, manufacturing intelligence and demand-dynamic performance. Computers & Chemical Engineering, 47: 145–156

De los Reyes A (2006). The role of computer-aided drafting, analysis, and design software in structural engineering practice. http://hdl.handle.net/1721.1/35080, 2016-10-25

Hinze J (2012). Construction Planning and Scheduling. 4th ed. Upper Saddle River: Prentice Hall

Hendrickson C, Au T (2008). Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects and Builders. Upper Saddle River: Prentice Hall

Kang H S, Lee J Y, Choi S S, Kim H, Park J H, Son J Y, Kim B H, Noh S D (2016). Smart manufacturing: past research, present findings, and future directions. International Journal of Precision Engineering and Manufacturing-Green Technology, 3(1): 111–128

Lohr S (2012). The age of big data. http://www.nytimes.com/2012/02/12/sunday-review/big-datas-impact-in-the-world.html?_r = 0, 2016-10-27

Manyika J, Chui M, Brown B, Bughin J, Dobbs R, Roxburgh C, Byers A H. (2011). Big data: the next frontier for innovation, competition, and productivity. http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/big-data-the-next-frontier-for-innovation, 2016-10-27

McAfee A, Brynjolfsson E (2012). Big data: the management revolution. Harvard Business Review, 90(10): 60–68

Merrow E W (2011). Industrial Mega-projects: Concepts, Strategies, and Practices for Success. Hoboken: John Wiley & Sons

Miller R, Lessard D R (2000). The Strategic Management of Large Engineering Projects: Shaping Institutions, Risks, and Governance. Cambridge: MIT Press

Moore G A (2014). In: Marketing and Selling Disruptive Products to Mainstream Customers. Crossing the Chasm. 3rd ed. New York: Harper Collin Publishers

Moorthy J, Lahiri R, Biswas N, Ghosh P. (2015). Big data: prospects and challenges. Vikalpa., 40(1): 74–96

NAE. (2008). Grand challenges for engineering. http://www.engineeringchallenges.org/File.aspx?id = 11574&v = ba24e2ed, 2016-10-27

Rujirayanyong T, Shi J (2006). A project-oriented data warehouse for construction. Automation in Construction, 15(6): 800–807

Siegel E (2013). Predictive Analytics: The Power to Predict Who Will Click, Buy, Lie, or Die. Hoboken: John Wiley & Sons