BIG DATA IN CIVIL ENGINEERING: A STATE-OF-THE-ART SURVEY

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Abstract. Data generation has increased drastically over the past few years. Data management has also grown in importance because extracting the significant value out of a huge pile of raw data is of prime importance while making different decisions. This article reviews the concept of Big Data. The Thomson Reuters Web of Science Core Collection academic database was used to overview publications that contained "BIG DATA" keywords and were included in Web of Science Category under "Engineering". The analysis of publications was made according to year, country, journal, authors, language and funding agency.

Keywords: engineering, Big Data, Web of Science.

Introduction

Generating of information from gained data is vitally important in terms of regulating life. Especially business enterprises need to store and transform data quickly and properly into information bases in order to achieve the objectives such as to be more competitive in the market, produce new products and be innovative. The increase in the amount of data sources also increases the amount of the data acquired. Therefore, storing and processing data has become difficult and classical approaches remain incapable to do it. Large amounts of data with a wide range can be stored, managed and processed using Big Data. Besides, Big Data ensures delivering proper information quickly and offers advantage and convenience to firms, researchers and consumers by taking the properties of Volume, Value, Variety, Veracity and Velocity into consideration (Ozkose *et al.* 2015).

1. Understanding of Big Data

Big Data is defined differently in literature. There is a number of definitions: Big Data is the amount of data beyond the ability of technology to store, manage and process efficiently. 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. Big Data Technologies are new generation technologies and architectures which were designed to extract value from multivariate high volume data sets efficiently by providing high speed capturing, discovering and analysing. As the definitions suggest, there are some points to be taken into consideration in Big Data sets. The data should be complex and multiple, and be of considerable size. Therefore conventional methods have difficulty in analysing Big Data sets and new methods and technologies are needed (Ozkose *et al.* 2015).

Big Data is a term for large and complex data sets, from music downloads to medical records and social media messages. Big Data is usually described by the four V's:

1. Volume: scale of data;
2. Velocity: analysis of streaming data;
3. Variety: different forms of data;
4. Veracity: uncertainty of data (Moreno-Sandoval *et al.* 2015).

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Big Data can be divided into 5 classes, regarding their characteristics: Data Sources (Web & Social, Machine, Sensing, Transactions and IoT), Content Format (Structured, Semi-Structured and Unstructured), Data Stores (Document-oriented, Column-oriented, Graph based and Key-value), Data Staging (Cleaning, Normalization and Transform) and Data Processing (Batch and Real time) (Ozkose *et al.* 2015).

Big data are worthless, if not managed and analysed for extracting useful information. Gandomi and Haider (2015) divide the overall process of extracting insights from big data into five stages, as shown in Figure 1. These five stages form the two main sub-processes: data management and analytics. Data management involves processes and supporting technologies to acquire and store data and to prepare and retrieve it for analysis. Analytics refers to techniques used to analyse and acquire intelligence from big data (Gandomi, Haider 2015).
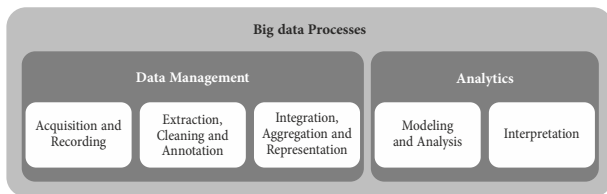

Fig. 1. Big Data process (Gandomi, Haider 2015)

There are several methods of the Big Data analysis, based on ways of data acquisition: text analytics, audio analytics, video analytics, social media analytics, and predictive analytics. Ozkose *et al.* (2015) define those methods as follows:

- Text analytics is used for information retrieval from data. E-mails, blogs, online forums, news and call center records are all examples of text data. Text analytics involve machine learning, statistical analysis and computational linguistics. Text analytics enable to extract meaningful summaries from large scale data. Information Extraction, Text Summarization, Question Answering and Sentiment Analysis are some of the techniques used in text analytics.
- Audio Analytics is used to extract information from unstructured audio data. Call centers and health services are commonly used utilization areas of audio analytics. Audio analytics can be used in numerous fields such as increasing the customer experience, the performance of cus-

tomer representative and the sales rate; comprehending several tasks such as customer behaviors and the troubles of products.
- Video analytics is the usage of various techniques to extract meaningful information, track and analyze video streams. Marketing and operations management is the main application area of video analytics.
- Social media analytics is the analysis of the structured and unstructured data on the social media channels. Social media can be categorized as follows Social networks (Facebook, LinkedIn), Blogs (BlogSpot, WordPress), Microblogs (Twitter, Tumblr), Social news (Digg, Reddit), Social bookmarks (Delicious, StumbleUpon), Media sharing (Instagram, YouTube), Wiki (Wikipedia, Wikihow), Question-and-answer sites (Yahoo! Answers, Ask.com), Review sites (Yelp, TripAdvisor).
- Predictive analytics is based upon estimating future considering current or stale data. Predictive analysis is used to capture the relationships of data and discover the patterns. Predictive analytics which is primarily based on statistical methods is highly applicable on many disciplines.

Big Data is used efficiently in many fields of activity, such as: automotive industry; hi-tech; oil and gas industry; telecommunication sector, medicine and healthcare; media and show business; travel and transport sector; social media and online services; information and communication sector. One of the fields where Big Data can be sourced and transformed into the useful information is Civil Engineering.

2. Research methodology

In this paper, the literature related to Big Data has been reviewed comprehensively on the basis of papers referred in Thomson Reuters Web of Science academic database. Following the methodological analysis (Fig. 2) on the entire body of collected publications, a number of articles were reviewed from the first international publications in the area to date (January 2016). The presented research attempts to answer the following questions: (1) How have the papers been distributed by the period of publishing? (2) How have the papers been distributed by country? (3) How have the papers been distributed by author? (4) How have the papers been distributed by journal? (5) How have the papers been distributed by funding agency?
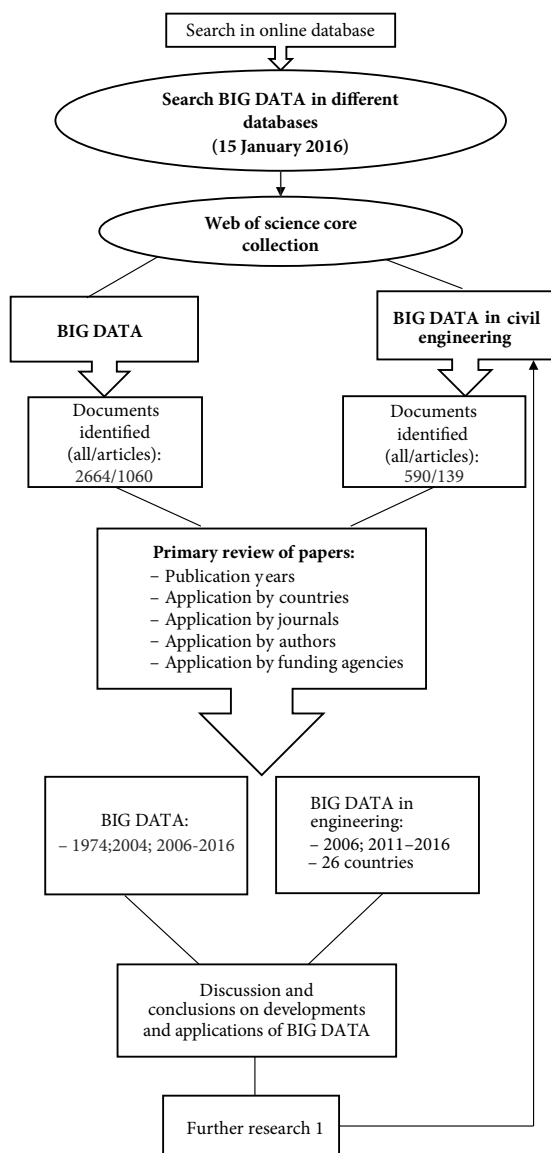
Fig. 2. Summary of the research procedure

3. Number of publications by different databases and by year

The analysis of the subject of Big Data has been done online. 5160 publications were found, including articles (1619) in different databases (Fig. 3).

Mainly publication were found in Web of Science database. It contains 2664 referred publications (Fig. 4) on the topic of Big Data (15 January 2016), covering all types of documents, including articles (1060) (Table 1).

Table 1. Publications on the topic of Big Data in Web of Science database

Publications on Big Data	Number of Publications
All	2664
Articles	1060
Publications on Civil Engineering	
All	590
Articles	139

As depicted in Figure 3, the first scientific research on the topic of BIG DATA was done in 1974. The extent of research in the area has been rapidly increasing during the last ten years. Numbers of publications on BIG DATA increased from one-to-two papers per year up to 110 in 2012. More than 90 per cent of publications were published in the last three years (2013–2015).

As depicted in Figure 5, the first scientific research on the topic of Big Data in Civil Engineering was done in 2006. The extent of research in the area has been rapidly increasing during the last ten years, mostly in 2013 (195 articles per year).
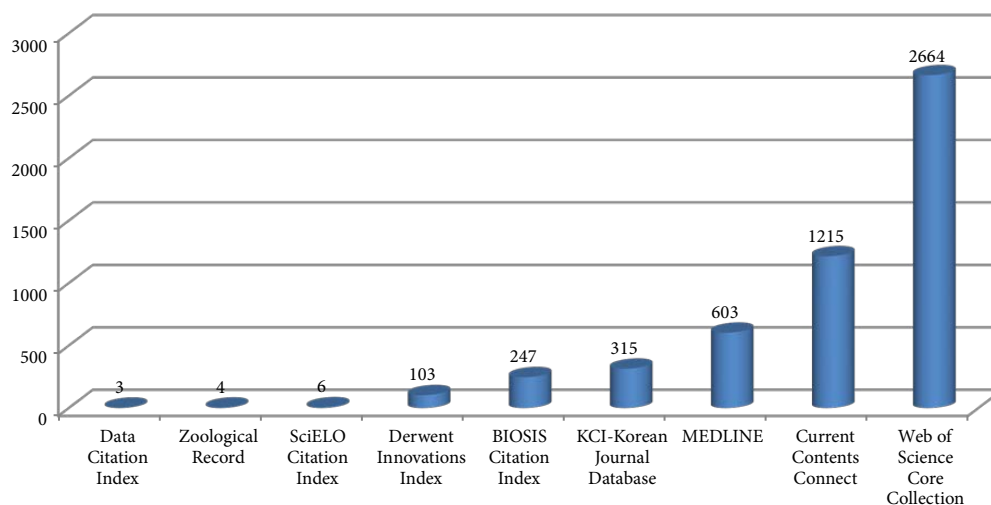

Fig. 3. Number of publications on the "BIG DATA" topic in different databases (total: 5160)
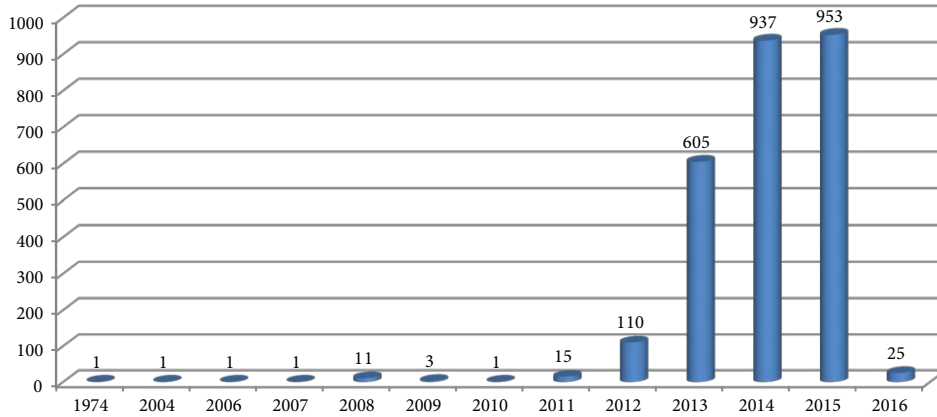
Fig. 4. Number of publications on the "BIG DATA" topic in Web of Science Core Collection database by year (total: 2664)
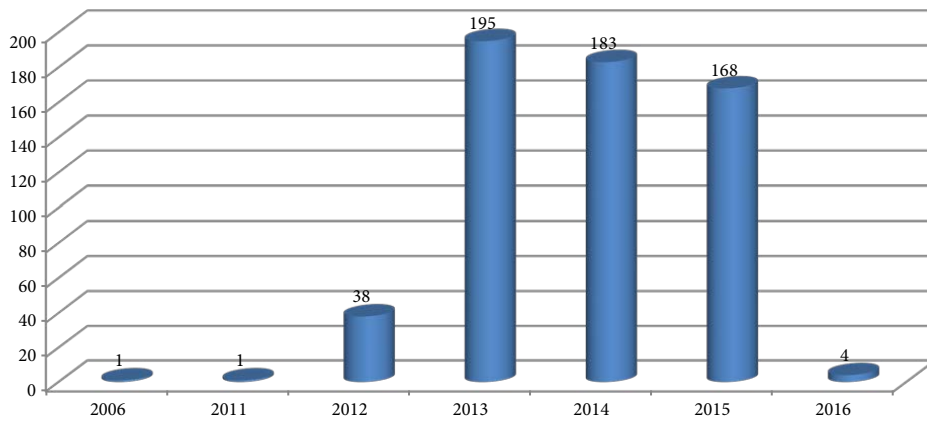

Fig. 5. Number of publications on the "BIG DATA + Civil Engineering" topic in Web of Science Core Collection database by year (total: 590)

4. Number of publications: by country, author, journal, funding agency

Further, the analysis focused on the use of "BIG DATA + Civil Engineering" topic by country. The information is given in Figure 6. Articles were an-nounced by researchers representing twenty six coun-tries of the world. The leader is USA, where authors published 39 articles.

Authors listed in Table 2 published their articles on the topic of using Big Data in Civil Engineering.
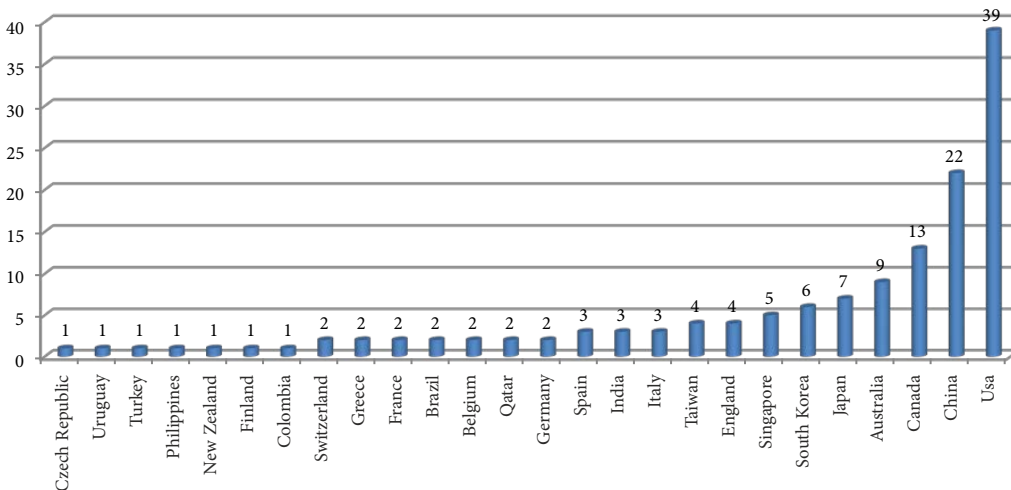

Fig. 6. Number of articles on the "BIG DATA + Civil Engineering" topic in Web of Science Core Collection database by countries/ territories (total: 139)

The table demonstrates that Zhang XY and Chen JJ are leaders of this particular topic. They published 5 articles per each.

Table 3 provides information on journals in ISI Web of Science database, which issued articles on the Big Data use in Civil Engineering. In total, articles were published in 73 journals. The majority of articles – 15 – were published announced in *IEEE Network*. The second place, with 6 publications, is occupied by the *International Journal of Production Economics* and *IEEE Transactions on Knowledge and Data Engineering*.

Table 4 shows the number of publications on using Big Data in Civil Engineering in Web of Science Core Collection database by funding agencies. In total, articles were funded by 84 agencies. The leader is National Natural Science Foundation of China (20 articles). The second place, with 8 publications, is occupied by the National Science Foundation.

Table 2. Number of publications on the "BIG DATA + Civil Engineering" topic in Web
of Science Core Collection database by author

Author's name	Number of articles
Zhang XY, Chen JJ.	5
Giannakis GB, Liu C.	4
Slavakis K, Mateos G, Xu M, Cai H, Yang C, Dou WC.	3
Scutari G, Facchinei F, Wang W, Mu JS, Jeong YS, Herrera F, Del Rio S, Chen G, Anonymous, Wu XD, Wu GQ.	2
Xu J, Xu C, Xin JC, Wolff I, Wang S, Wang FY, Walter T, Vinsel L, Van Der Schaar M, Tsuda T, Tsuchiya S, Tsuchimoto Y, Triguero I, Traganitis PA, Tractenberg RE, Thilmany J, Tao F, Tanaka T, Tan KH, Taisch M, Sun JS, Sun J, Steinmann M, Stanek D, Song BY, Shi H, Shahabi C, Schmidt M, Schlieski T, Sato N, Sandryhaila A, Samuelson N, Sakamoto Y, Sait SY, Sagratella S, Liu Y, Liu JK, Liu JC, Liang S, Li ZX, Li Y, Li RM, Li JR, Li H, Lee V, Lee S, Lanman C, Kundu MK, Kumar PER, Kim SJ, Kim M, Kim HJ, Kim AS, Kido A, Ki SJ, Khare S, Kayahara A, Kang WW, Jones-Farmer LA, Johnson BD, Ji GJ, James C, Jackson K, Inoue S, Imai S, Huang GQ, Horta EG, Hong YL, Hong MY, Xian HJ, Sohn MD, Shin SS, Shibata T, Lan SL, Kurachi T, Kungurtsev V, Hazen BT, Han TT, Guo S.	1

Table 3. Number of publications on the "BIG DATA + Civil Engineering" topic in Web of Science Core Collection database by journals total: (139)

Source titles	Number of articles
IEEE Network	15
International Journal of Production Economics	6
IEEE Transactions on Knowledge and Data Engineering	6
Mathematical Problems in Engineering	5
IEEE Signal Processing Magazine	5
Tsinghua Science and Technology	5
Transportation Research Part C Emerging Technologies	5
IEEE Transactions on Parallel and Distributed Systems	5
IEEE Intelligent Systems	5
IEEE Transactions on Signal Processing	3
Technology Review	3
Sea Technology	3
International Journal of Communication Systems	3
IEEE Transactions on Computers	3
IEEE Communications Magazine	3
Fuzzy Sets and Systems	3
Mechanical Engineering	2
IEEE Transactions on Semiconductor Manufacturing	2
IEEE Journal of Selected Topics in Signal Processing	2
Fujitsu Scientific Technical Journal	2
Other 53 journals*	1

Notes: *The following journals have one article each: Proceedings of the IEEE, Manufacturing Engineering, Korean Journal of Chemical Engineering, Journal of Modern Power Systems and Clean Energy, Journal of Industrial Ecology, Journal of Engineering Education, Ite Journal Institute of Transportation Engineers, International Journal of Production Research, International Journal of Advanced Manufacturing Technology, IEEE Transactions on Intelligent Transportation Systems, IEEE Transactions on Image Processing, IEEE Spectrum, Eurasip Journal on Advances in Signal Processing, Etri Journal, Esa Bulletin European Space Agency, The Korean Journal of Chemical Engineering, Scientific American, Revista Facultad de Ingenieria, Power, Pattern Recognition, Neuron, Multimedia Tools and Applications, Journal of the Institute of Telecommunications Professionals, Journal of Supercomputing, Journal of Sensors, International Journal of Software Engineering and Knowledge Engineering, Information an International Interdisciplinary Journal, IEEE Transactions on Information Forensics and Security, IEEE Transactions on Biomedical Engineering, IEEE Transactions on Bio Medical Engineering, Solid State Technology, Science and Engineering Ethics, Sadhana Academy Proceedings in Engineering Sciences, Quality Engineering, Ergonomics, Environmental Science Technology, Environmental Modelling Software, Desalination, Bell Labs Technical Journal,

Applied Energy, Advances in Mechanical Engineering, Transportation Research Record, Transportation Research Part D Transport and Environment, IEEE Journal on Selected Areas in Communications, Engineering Technology Applied Science Research, Energy Policy, Computers Electrical Engineering, Cloud Services Networking and Management, Chemical Engineering News, Applied and Computational Harmonic Analysis, Ambio.

Table 4. Number of publications on the "BIG DATA + Civil Engineering" topic in Web of Science Core Collection database by funding agencies total: (139)

Funding Agencies	Number of articles
National Natural Science Foundation of China	20
National Science Foundation	8
NSFC	6
Fundamental Research Funds for the Central Universities	5
National Science Foundation of China	4
Beijing Natural Science Foundation	4
National Basic Research Program of China	3
Australian Research Council	3
US National Science Foundation	2
Tianjin Younger Natural Science Foundation	2
SRF for Rocs Sem	2
National Key Technology R D Program of the Ministry of Science and Technology	2
National Key Basic Research and Development 973 Program of China	2
National 973 Program of China	2
Muri	2
Miur Project Platino	2
European Commission	2
Basic Science Research Program Through The National Research Foundation of Korea NRF Ministry of Education Science and Technology	2
Other 66 funding agencies	1

Notes: *The following funding agencies have one article each: Zhejiang Provincial Government, Wolf Creek Foundation, USA NSF Grant CMS, USA NSF Grant Career Award, USA National Science Foundation, US National Science Foundation NSF, United States Department of Agriculture National Agricultural Library, UK EPSRC Digital Economy Programme, U S Doe, U S Department of Energy Doe, Tsinghua Toshiba Energy and Environment Research Center, Toward World Class Universities Project of NTHU, Torres Quevedo Program, Tianjin Natural Science Foundation, Talent Projects of the Educational Department of Liaoning Province, Taiwan Semiconductor Manufacturing Company, Swiss Science Foundation, Strategic Priority Research Program of the Chinese Academy of Sciences, Strategic International Collaborative Research Program Sicorp Japanese JST U S NSF Joint, Research Big Data and Disaster Research BDD, Special Fund for Meteorological Research in the Public Interest from Ministry of Science and Industry of China, Spanish Ministry of Education Under a Fullbright Grant, Spanish Ministry of Education and Science, Social Sciences and Humanities Research Council of Canada SSHRC,

Shenzhen Foundational Research Projects, Seaver Institute, RWTH Research Fellowship Funded Through the Excellence Initiative of the German Federal and State Governments, RWTH Aachen University Through the UMIC Research Center, RGC Hong Kong, RGC HK, RGC GRF Polyu, Ramco Cements Limited, Qinhuangdao Traffic Management Bureau, Provincial Natural Science Foundation, Program for Excellent Talents in Beijing, Program for Changjiang Scholars and Innovative Research Team in University PCSIRT of the Ministry of Education of China, Professor Nigel H M Wilson of Massachusetts Institute of Technology, Privacy Aware Retrieval and Modelling of Genomic DATA, Postdoctoral Science Foundation of China, PHR, NSFC Innovation Research Group, NSF US, NSF Grants, NSF China, NSF, NSERC Strategic Project Grant, NSERC Discovery Grant, NSERC Canada, NPRP from the Qatar National Research Fund a Member of the Qatar Foundation, Nottingham University Business School Spark Fund, NIH Nida, NCETFJ, NCET, Natural Sciences and Engineering Research Council of Canada NSERC, Natural Science Foundation of USA, Natural Science Foundation of Fujian Province of China, Natural Science Foundation of Fujian, National University of Singapore Research Grant, National Training Program of Innovation and Entrepreneurship for Undergraduates, National Science Foundation of the US, National Science Foundation for Distinguished Young Scholars of China, National Science Council of Taiwan R O C, National Research Foundation of Korea NRF Korea Government MSIP, National Natural Science Foundation of China A3 Program, National Natural Science Foundation, National High Tech Research and Development 863 Program of China, National Center for Research Resources, FP7 Calipso European Project, Fapemig, European Union, European Social Fund, ERM Group Foundation, ERC, Dupont Young Professor Grant, DOW Sustainability Fellowship Program, DOD, Department of Science and Technology DST Government of India, Department of Industry Australia, Department of Energy, CSIRO Office of Chief Executive Top up PHD Scholarship, Comba Fund, Collaborative Innovation Center for Capital World City S Smooth Traffic Construction, Cityu Teaching Development Grant.

Conclusions

The first scientific research on Big Data was done in 1974, but the main research started only in early 2000.

The breakthrough in Big Data occurred only in 2012.

Currently, Thomson Reuters Web of Science Core Collection quotes 2664 publications on a topic of Big Data, 1060 of which are articles.

The interest in the topic of Big Data in Civil Engineering rapidly increases, 590 articles in Thomson Reuters Web of Science Core Collection were categorized as part of this topic beginning from 2006.

Most publications (39) were announced by researchers in the USA. The second place is occupied by Chinese researchers with 22 publications.

The majority of publications (15) were printed in the IEEE Network journal. The second place, with 6 articles, is occupied by the *International Journal of Production Economics* and *IEEE Transactions on Knowledge and Data Engineering*.

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