5G Enabled Manufacturing Evaluation for Data-Driven Decision-Making

Citation for the original published paper (version of record):
Bärring, M., Lundgren, C., Åkerman, M. et al (2018). 5G Enabled Manufacturing Evaluation for Data-Driven Decision-Making. Procedia CIRP, 27: 266-271.
http://dx.doi.org/10.1016/j.procir.2018.03.169

(article starts on next page)

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 72 (2018) 266–271

www.elsevier.com/locate/procedia

51st CIRP Conference on Manufacturing Systems

5G Enabled Manufacturing Evaluation for Data-Driven Decision-Making

Maja Bärring[a]*, Camilla Lundgren[a], Magnus Åkerman[a], Björn Johansson[a], Johan Stahre[a], Ulrika Engström[b], and Martin Friis[c]

[a]*Chalmers University of Technology, Hörsalsvägen 7, Gothenburg 412 96, Sweden,* [b]*Ericsson AB, Lindholmspiren 11, Gothenburg 417 56, Sweden,* [c]*SKF Manufacturing Development Centre, Hornsgatan 1, 415 50 Gothenburg, Sweden*

* Corresponding author. Tel.: +46-723-50 93 41. *E-mail address:* maja.barring@chalmers.se

Abstract

Manufacturing industries are experiencing a technical paradigm shift that will change how they run their operations. Equipment and personnel generate an ever-increasing amount of data, and connectivity enables to utilize data to a larger extent. Connecting a machine is not a technical obstacle anymore, but with all available data, the challenge is to understand the requirements of data to support efficient decision-making. This paper will address the requirements of data by domain experts, in the context of more real-time data available. A focus group interview was performed, assessing key the factors of big data; volume, velocity, and variety of data.

Keywords: Data-driven decision-making, 5G, Big data

1. Introduction

More business activities today are digitalized, providing new sources of information and in combination with ever-cheaper equipment it will bring business into a new digital era. For data storage and processing technologies, it has in recent years undergone dramatic changes which impact on the possibilities of how to collect and leverage data. The data-intensive approach has previously been a costly process, but with a steadily declining cost of storage, memory, processing, bandwidth and other elements of computing, it has become more economical [1]. Within the manufacturing domain, the technology transformation is commonly referred to as Industry 4.0 and describes the use of ICT in the industrial context. The ambition is to generate knowledge from data that will support decision-making in all parts of the business [2].

To make sense of data in real-time involves detecting anomalies, noticing patterns, and predicting what will happen in a near future [3]. These new opportunities for handling and making data more accessible, impact on how decision-making can be done. From relying on intuition, decisions can in a higher degree be based on more and better data [1, 4]. Organizations can measure and know radically more about their business with big data, which improves decision-making and performance [1].

As the new technologies can deliver information faster, the identification of information of interest should be done fast as well [5]. Developers and business leaders tend to focus on the technological opportunities of new trends, instead of focusing on what the desired outcome is. What business or organizational problem that could be addressed with the new technology should be given attention [6].

This paper will address the requirements of data for driving decision-making for a manufacturing context. Method used is a focus group interview with domain experts, from the manufacturing company, evaluating how the real-time data extracted from a grinding machine can support data-driven decision-making. To set the context of how real-time data have been enabled, the connectivity solution applied in this research project is presented. The paper explains how a grinding machine has been connected to a cellular LTE network, which will be an inherent part of 5G, how data parameters from

10.1016/j.procir.2018.03.169

sensors and control system are collected, and how the data is presented to the operator.

2. Methodology

2.1. Testbed project

The 5G connected grinding machine is part of a research project, where Chalmers collaborates together with SKF and Ericsson AB. The main idea is to investigate how the next generation of telecommunication, i.e. 5G, can be applied to enable higher efficiency, flexibility, traceability, and sustainability in the manufacturing domain. The project is defined by four demonstrators. Three of them have been addressed in the study presented in this paper:

1. Network and cloud that ensure the infrastructure for communication and data handling
2. Stationary connectivity
3. Mobile connectivity

Network and cloud explain the cellular LTE network that has been deployed to enable higher connectivity of equipment and personnel and the cloud that possess data storage and analytic functionalities. The stationary connectivity is the connected grinding machine, which data are collected from, and the mobile connectivity demonstrator is the operator support system where data are presented to the operator.

2.2. Focus group

Focus group is a data collection method where a number of people are gathered at the same occasion to explore a topic more in depth. Compared to interviews, this way of raising questions encourages a discussion among the participants, which is desired for a focus group. An interview guide can be used for guiding the discussion based on the researcher's aim [7].

A focus group was used in this study to explore how decision-making is performed today and how data can be used in a future state to support decision-making. It was performed at the manufacturing company with four people during a two-hour long session. Employees selected for this exercise have different responsibilities and roles in the organization, and that selection was purposely done to get a wider discussion. An interview guide was used to aid the discussion. The first part of the interview, functionalities of the mobile connectivity demonstrator were explained and evaluated based on how they can bring value to the operator's work today and expected to do in the future. For the second part of the interview, questions were inspired by the existing literature on the topic of data-driven decision-making. Included references stress how the three key factors of big data can drive decision-making. It was therefore of interest to understand from a manufacturing perspective how volume, velocity, and variety of data can support decision-making today and are expected to do in the future. The interview guide and participant list with selection criteria can be found in Appendix A and B. The interview was recorded and transcribed to support the analysis of the answers.

3. Theory

3.1. Connectivity

Consumers' request for faster, smarter, and secure wireless network implies an increased demand for higher data rates [8]. Besides speed and security, connectivity should also enable users to stay connected [9]. The increased number of devices and applications connected with varying Quality of Service (QoS) needs, drive the current state of telecommunication to change [10]. To deal with these challenges, a new generation of telecommunication technology, 5G, is being developed.

3.1.1. Development of 5G and related work

5G will build on both the existing LTE technology, with higher maturity level, and the application of new key technologies in order to serve the demands from 2020 and beyond [11]. The standardization body 3rd Generation Partnership Project (3GPP) that had a leading position of standardizing the LTE network, is setting the standards for 5G as well [12]. For the future requirements, a number of use cases have been identified by Ericsson within the automotive industry, manufacturing, transportation, and retail to mention some [13].

From the uses cases, it has been identified that to manage high data rates is one requirement, but low latency in data delivery, efficient energy consumption scheme, high scalability to accommodate a large number of devices, and ubiquitous connectivity for the users are also important for 5G [11, 13]. The technical requirements of 5G has been defined as a system that is capable of 1000 times higher mobile data volume per area, 10 to 100 times higher number of connected devices, 10 to 100 times higher user data rate, 10 times longer life of battery (for low power massive machine communications), and 5 times reduced End-to-End latency [14]. Industry 4.0 describes a number of changes that will impact the manufacturing area, where the main drive will be IT-oriented [15]. The capacity for processing power, memory size, and network capacity is growing at an exponential rate at the same time as the cost for these components are falling in the same proportion [16].

3.2. Data-driven decision-making

To analyze data for making sense of what is happening in an organization is not a new phenomenon. Already in the 1970's the term decision support was adopted to refer to the use of analyzed data to support decision-making. At the present stage, the term big data is used where the focus is on very large, unstructured, and fast-moving data [17]. Just as for analytics before it, big data attempts to gain knowledge from data and translate it into business advantage for a company [1]. Since the idea of analyzing data to gain more knowledge of the organization is not new, what makes big data different compared to its predecessor?

3.2.1. What makes Big Data different?

One well-cited definition of big data is the one presented in a Gartner report from 2011 that refers to the three Vs of data; volume, velocity, and variety of data [18]. The *volume* of data implies the amount of data created every day, which has increased tremendously and keep doubling every 40 months. A source important for the data increase has mainly been from internet, but the same development can be seen internal within companies generating ever more internal data that can serve for data-driven decision-making [1]. *Velocity* refers to the speed data are generated but also how fast it should be analyzed and acted upon [19]. Data is coming in a continuous stream and it is of interest to make useful information of it in real-time [20]. The speed of data can be more severe for the business success than the volume. When the data becomes available in real-time, the organization could act in a more agile manner improving response time [1]. In the big data era, *variety* of data will become possible which refers to datasets with structural heterogeneity [19]. Data take the form of messages, updates, images, readings from sensors, location from cell phones etc. As the technology can record data from different sources, a variety of types of data will be available for the analysis [1]. Although all benefits that big data can bring, it should be kept in mind that the quality of data and how representative data are for the analysis intended are important for valid results [20].

As the data changes, the procedure of making use of it for internal decisions also has to adapt. For traditional decisions support, a data analyst used a set of data that was of interest in isolation and developed an appropriate model for the analysis to advise the decision-maker on the results obtained. In the current situation, big data are keeping flowing in a continuous flow resembling a fast-flowing stream [17]. The potential of big data can first be obtained when it is leveraged to drive decision-making. It will require an efficient process that can transform high volumes of fast and diverse data into insights that provide meaning to the organization [19]. Besides the consideration of how to collect data and make it to valuable information for the decision maker, it is also as vital to identify how the outcome of the analysis will facilitate the decisions and actions [17].

3.2.2. Domain knowledge

To understand what problems to address in an organization, the people that possess the domain knowledge are the ones who can identify where the biggest opportunities and challenges are. The domain experts are deeply acquainted with a specific area and they are therefore critical to advise for the purpose of identifying the right problems to tackle. These persons within in an organization need to be supplied with the right data from various sources in real-time to identify what problem it can solve [1]. When companies will be able to make decisions based on data instead of intuition will be a clear indicator of the value of big data for organizations [4].

4. Connectivity

4.1. Network and cloud

A dedicated 4G LTE network has been deployed and an overview of the connectivity for one site is shown in Fig.1. At the factory, a grinding machine has been connected to a cellular LTE network exploiting LTE modems. Mobile phones are also connected to the LTE network. The distributed IoT platform Calvin is the platform used for data collection [21]. A local client server exists in the factory for intermediate storage. Over the radio link, data are sent to where the database is geographically located, ca. 250 km away in Lund, and stored in the cloud. The analytics platform, which holds the analytics capabilities, is geographically located ca. 450 km away in Stockholm and performs the analysis and anomalies detection. Real-time machine data are presented to the machine operator in the mobile operator support system client.

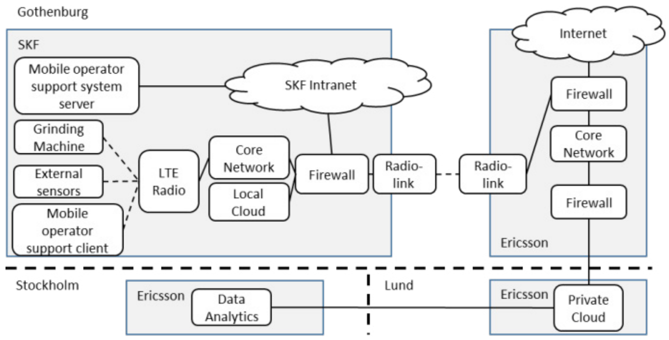

Fig. 1 Illustration of the connectivity infrastructure and equipment connected

4.2. Data parameters selected for the analysis

The used grinding machine for this study is a double face grinding machine, and critical components of the machine are ball screws, slides, and the motor. As these components are worn out they are causing vibrations, resistance, uneven movements and temperature increase when machining. These circumstances can lead to quality issues of the product, which in turn can result in rework of the product or even scrap. Since there are several possible indications resulting in quality deviations, it makes it complex for the machine operator to identify the right actions in order to avoid a potential quality problem. The current way of taking proactive actions to avoid a quality problem often involve decreasing the feeding rate in the machine which implies speed losses. It does not either imply that the cause of the quality issue is identified, which may involve longer machine downtimes due to maintenance efforts.

To provide more insights to the operator to support decision-making, a number of data parameters have been selected that can indicate problems with the components ball screws, slides, and motor. These data parameters are motor temperature, the torque of the motor, the position of slides, and the vibration in slides and motors. An additional data parameter that will be connected is the measuring machine that indicates if any corrective actions are needed when manufacturing. Data collected, analyzed and transformed to information will support the operator to take the right decision.

4.3. 5G connected grinding machine

As the overarching communication paths, with infrastructure hardware, cloud storage and analytics platform were installed, the connection on machine level was identified and implemented. The technical solution for connecting the machine was guided by the selected data parameters for analysis. An overview is illustrated in Fig. 1.

To collect data on vibrations in the machine, IMX was chosen as a solution. IMX is a product that analyzes vibrations for bearing applications. It consists of vibrations sensors mounted in the grinding machine, a hardware that collects the data and a software that can process the data. For this case, the IMX hardware was connected to a laptop that contains the IMX software to manage the vibration data, which is connected to a router with a USB-stick communicating over the radio cellular network. Motor temperature, torque, drive load of motor and position, are data parameters that are already collected by the control system in the machine, and these can be extracted to the cloud. The grinding machine is connected to a router with a USB-stick communicating over the radio network. OPC UA is the industrial standard for communication and valid for the data parameters recently explained. Measurement data is extracted from a stand-alone measurement machine next to the grinding machine and is connected to the machine computer.

5. Mobile operator support system

Extracted real-time data are sent back to the mobile operator support client. For this study, smartphones have been used as ICT-tools connected to the cellular LTE network. An already existing mobile operator support system (utilizing apps) has been used with a number of functionalities added that can test the data-driven approach to support the machine operator. Three of the functionalities are further explained in this section; compensation for tolerance offset, presentation of vibration data, and cycle times for the grinding process.

5.1. Tolerance offset

One view in the mobile operator system can display the measurement of the machined surface of the product. Based on the value the operator can take action to compensate for any tolerance offset. It can be done with the two options of either plus or minus compensation in the mobile unit. As required actions have been done, the window freezes and no more compensation can be done until the compensated value is returned back to the view. This enables the operator to be both informed and take action regardless of physical location in the workshop.

5.2. Vibration data

In this view, vibration data of spindles and motors are presented in real-time to the operator. If vibrations appear it constitutes a severe problem since it can cause many subsequent errors impacting on, for instance, the quality of the product. As a peak occurs in the vibration data the operator can be informed by an alarm from the operator support system that something may have happened that is out of the ordinary. By analyzing the data an understanding of the need for replacing machine components can be gained. It can also provide support to the operator when a collision has happened in the machine.

5.3. Cycle times

In this functionality, the purpose is to present data about the actual cycle time for a machine and cell. Cycle times will be presented for individual cycles such as the approach of tool and different grinding operations. This will provide data that can be used for the understanding of cycle time variation that may be impacted by the product manufactured.

6. Results from the evaluation by domain experts

6.1. The functionalities

Real-time data are presented to the operator in the three functionalities explained, and to understand the applicability and value of receiving data in real-time, a focus group interview was performed. The two questions were (1) what the value of using the functionality would be today and (2) how it can be useful for the future role of the operator. The aim was to understand how access to data in the mobile device can bring value to the organization today and in the future. The answers are presented for respective functionality evaluated in Tables 1, 2, and 3.

Table 1. Results from evaluation of tolerance offset by domain experts

Question	Tolerance offset
1	It will support flexibility and mobility for the operator. The operator will be informed and can act regardless of location in the workshop.
2	In the future, it will be even more important for the operator to be able to monitor the machine and preferably anywhere in the workshop.

Table 2. Results from evaluation of vibration data by domain experts

Question	Vibration data
1	The value would be to have less unplanned stop because of machining errors. It can also be a valuable input to understand the lifespan of a tool.
2	To be able to plan better and avoid unplanned stops.

Table 3. Results from evaluation of cycle times by domain experts

Question	Cycle time
1	To know the actual cycle time is of interest to the managers and production technicians for follow-up. It is a way to understand how the designed system actually performs in reality.
2	In the future, this will provide a historical basis to support continuous improvements.

6.2. Volume, velocity, and variety of data

The importance of receiving big volumes of data, high speed of data, or a big variety of data was also discussed with the same focus group. It was first discussed how data are used for decision-making today and how it is anticipated to be used in the future. Results are presented in Table 4.

The question about how decisions are done today was answered by the focus group as mainly based on their intuition and experience. To work more with data as a decision support will require new way-of-working and systems to support. An expected change for the future production setup will be to base the decision-making more on data instead of estimating and base it on the intuition. One example mentioned where the focus group believes more data can support is the understanding of problems connected with the machine in correlation with numbers of products manufactured. This is not evaluated today because the data is missing or not recorded. It could also give a better forecast of the expected lifetime of a tool or component of the machine, which in turn means that it can be replaced in time. It will facilitate a better planning horizon both for the internal organization but also in the communication with external partners such as machine vendors.

Table 4. Results from evaluation of volume, velocity, and variety of data

Question	Current state	Future state
Data or intuition	Mainly based on intuition. Maintenance has started to collect more data.	More data-driven decision-making.
Volume	For production technicians and maintenance, it is the volume that will play an important part to drive decision-making.	More data will become increasingly important as the organization learns more from the data.
Velocity	It is important for the daily decision-making.	For the operator, the speed of data will be important.
Variety	Data sources used today is a system where the operators manually add information about status when the shift is finishing. There is also oral communication between the personnel.	Variety of data sources will be important in the future, to extract and analyze data from various sources for analysis and decision-making.

A comment during the focus group interview was the importance of receiving the right data with the right resolution to support decision-making. Data presented with a resolution that does not correspond to the needed one on e.g. cycle times may lead to the wrong conclusions or not support the intended decision.

A concluding question about how to use data to drive decision-making was whether there is any tradeoff between the quality and the speed of data. The answer was that it depends on the decision and what kind of support it requires. If the quality of the data is poor, then the likelihood that the speed would be valuable is questionable. There are situations, however, where the speed can be more important. To take one example, the resolution of a picture can be of less quality but the speed of how fast the operator can receive it in order to act is more important. Another example is when a collision in a machine happens, where it can be more important to be informed at a first stage that it has happened rather than why it has happened. To understand what has happened will be more important in the next stage for the analysis to find the root cause.

7. Discussion

This paper addresses the requirements of data for driving decision-making for a manufacturing context. The method used is a focus group interview with domain experts, from the manufacturing company, evaluating how the real-time data extracted from a grinding machine can support data-driven decision-making. To set the context of how real-time data have been enabled, the connectivity solution applied in this research project is presented.

It was identified from the focus group interviews that the decision-making made today by the operator is mainly based on the experience and intuition. The understanding of a future situation, however, is that data will play a more decisive role in decision-making. This applies not only to the production but also for other departments that can gain more knowledge about their processes by using data. Another function is in the communication with external partners, such as machine vendors. With better data of the production, a better understanding of the own processes can be gained that could simplify communication with machine vendors when problems occur.

The participants of this study were selected to bring different perspectives to the discussion about requirements of data for driving decision-making in a manufacturing context. The machine operator and production manager represented the user. The project manager and app developer represented the intended project outcome of having more data. During the discussion, the combination of roles facilitated a discussion that could both address important aspects on the detailed level, but also from a holistic perspective of how more real-time data can benefit the organization. It should be noted that the focus group interview was performed with four participants this time. To gain more scientific validity a future research would require more participants to support the results identified. It was also raised during the interview, that the participation from other departments with close connection to manufacturing, e.g. maintenance and production technicians would add value to the discussion.

Three key factors that are proposed to distinguish big data from traditional data analytics are volume, velocity, and variety of data. The importance of these for decision-making was evaluated by the domain experts. From the results, it was seen that volume is expected to be important, especially for the analysis that will support maintenance and production technicians. The speed of data is important for the operator in the daily operations in order to receive data fast to support immediate decision-making. The variety of data is also expected to become important in the future state where more data will be used. Besides the three key factors, it was also stressed that the right data should be identified and presented in the right resolution to facilitate that the data can be interpreted. A tradeoff between speed and quality can also be possible when a decisive factor is to know that something has happened rather than what has happened.

8. Conclusions and future work

The question addressed in this paper is to further understand the requirements of data to support decision-making when more data becomes available. From the results it can be concluded that data is expected to play a more decisive role for decision-making in the future production setup. All three key factors for big data are seen as important for the requirements of data, but volume is more important for the trend analysis and velocity in the daily operations. It was also stressed that the right data to be used is a major precondition for making use of data.

For a future study, it would be of interest to understand how the requirements of data that support decision-making have an impact on the requirements of the connectivity, for instance, 5G. If the velocity of data is important what does that imply for an acceptable latency? The request for big data volumes, what does that demand from the network's capability to handle high data rates?

To evaluate the requirements of data to drive decision-making, the definition of big data was used, i.e. volume, velocity, and variety of data. To identify how data can drive decision-making in the manufacturing domain, it would be of interest to investigate other specifications of data as well in a future study.

Acknowledgements

This study has been funded by the Swedish Agency for Innovation Systems (VINNOVA) and their strategic program for sustainable Swedish production (Produktion 2030). The work presented in this paper has been carried out within the Production Area of Advance at Chalmers University of Technology. The support is most gratefully acknowledged.

Appendix A. Interview guide

A.1. Evaluation of functionalities in operator support system

1. What would the value be of using it?
2. How can it be useful for the future role of the operator?

A.2. Volume, velocity, and variety of data

Current situation:
1. How are decisions made?
    1.1. Based on data?
    1.2. Based on intuition and experience?
2. How important is the volume of data for decision-making?
3. How important is the velocity of data for decision-making?
4. What are data sources used?

Future situation:
1. How are decisions expected to be done?
    1.1. Based on data?
    1.2. Based on intuition and experience?
2. How important will the volume of data be for decision-making?
3. How important will the velocity of data be for decision-making?
4. How important will the variety of data be for decision-making?
5. Is there any tradeoff between quality and speed of data?

Appendix B. Participants in focus group interview

Participant	Selection criteria
Project manager	Representative of the research project with the knowledge of the intended effect of the project
App developer	Explained the functionalities and represents the intended outcome of the functionalities developed
Manager production line	Represents the production area of interest; grinding operations
Machine operator	Represents the machine operator perspective for the grinding operations

References

[1] McAfee A, Brynjolfsson E, Davenport TH. Big data: the management revolution. Harvard business review. 2012;90(10):60-8.
[2] Schuh G, Anderl R, Gausemeier J, ten Hompel M, Wahlster W. Industrie 4.0 Maturity Index. 2017.
[3] Davenport TH, Kirby J. Just How Smart Are Smart Machines? MIT Sloan Management Review. 2016;57(3):21.
[4] Brynjolfsson E, McElheran K. The Rapid Adoption of Data-Driven Decision-Making. American Economic Review. 2016;106(5):133-9.
[5] Davenport TH, Snabe JH. How Fast and Flexible Do You Want Your Information, Really? MIT Sloan Management Review. 2011;52(3):57-62.
[6] Patel M, Jason S; Christopher T. What's new with the Internet of Things? McKinsey&Company2017 [Available from: https://www.mckinsey.com/industries/semiconductors/our-insights/whats-new-with-the-internet-of-things.]
[7] Bryman A, Bell E. Business research methods: Oxford University Press, USA; 2015. pp. 512-522
[8] Akyildiz IF, Gutierrez-Estevez DM, Balakrishnan R, Chavarria-Reyes E. LTE-Advanced and the evolution to Beyond 4G (B4G) systems. Physical Communication. 2014;10:31-60.
[9] Boccardi F, Heath RW, Lozano A, Marzetta TL, Popovski P. Five disruptive technology directions for 5G. IEEE Communications Magazine. 2014;52(2):74-80.
[10]Series M. IMT Vision–Framework and overall objectives of the future development of IMT for 2020 and beyond. 2015.
[11]'5G White Paper.' In., edited by Rachid El Hattachi and Brian Daly.
[12]Akyildiz IF, Nie S, Lin S-C, Chandrasekaran M. 5G roadmap: 10 key enabling technologies. Computer Networks. 2016;106:17-48.
[13] '5G radio access – capabilities and technologies.' In. 2016. Ericsson White paper.
[14]Osseiran A, Braun V, Hidekazu T, Marsch P, Schotten H, Tullberg H, et al., editors. The foundation of the mobile and wireless communications system for 2020 and beyond: Challenges, enablers and technology solutions. Vehicular Technology Conference (VTC Spring), 2013 IEEE 77th; 2013: IEEE.
[15]Lasi H, Fettke P, Kemper H-G, Feld T, Hoffmann M. Industry 4.0. Business & Information Systems Engineering. 2014;6(4):239-42.
[16]Kagermann H. Change through digitization—Value creation in the age of Industry 4.0. Management of permanent change: Springer; 2015. p. 23-45.
[17]Davenport TH. Big data @ work: dispelling the myths, uncovering the opportunities. Boston, Massachusetts: Harvard Business Review Press; 2014. Pp. 9-10, 16-18, 203
[18]Laney D. 3D data management: Controlling data volume, velocity and variety. 2001.
[19]Gandomi A, Haider M. Beyond the hype: Big data concepts, methods, and analytics. International Journal of Information Management. 2015;35(2):137-44.
[20]Fan W, Bifet A. Mining big data: current status, and forecast to the future. ACM sIGKDD Explorations Newsletter. 2013;14(2):1-5.
[21] Persson P, Angelsmark O, editors. Calvin–merging cloud and iot. Procedia Computer Science; 2