Jurnal Kejuruteraan 34(1) 2022: 1-10
https://doi.org/10.17576/jkukm-2022-34(1)-01

Essential Elements for Radio Frequency Identification (RFID) adoption for Industry 4.0 Smart Manufacturing in Context of Technology-Organization-Environment (TOE) Framework – A Review

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Received 12 March 2021, Received in revised form 12 July 2021
Accepted 12 August 2021, Available online 30 January 2022

ABSTRACT

Automatic identification and data collection provides an ideal basis for Industry 4.0 Smart Manufacturing. The manufacturing sectors, involving a wide spectrum of physical and digital world, are functioning in extremely challenging environment. To optimize production efficiency, the incorporation of automated data collection technologies such as Bar Code and Radio Frequency Identification (RFID) is essential. Both these technologies have a great overlap in terms of industrial applications and no study reviews the existing literature in this regard. Therefore to cope up this matter, a systematic literature review has been conducted in which the technologies have been studied and compared, followed by the detailed discussion under various contexts of Technology-Organization-Environment (TOE) Framework. It has been observed that both these technologies have been employed in various manufacturing domains such as lean manufacturing, inventory management and production planning. However, it has been observed that RFID technology carried technological superiority over Bar Code technology. The systems utilizing the former are highly reliable, exquisitely capable and perform excellent in case of automation. However, issues such as high capital costs and increased level of technical complexity are few dilemmas in case of adopting RFID based systems. In addition to that, the implementation of RFID systems is complemented by certain essential features of TOE framework, which can help to elevate competitiveness and efficiency of an organization regarding tracking and identification of assets and inventory.

Keywords: Radio Frequency Identification (RFID); Barcode Technology; Technology-Organization-Environment (TOE) Framework

INTRODUCTION

Role of automated data identification and data capturing technologies is indispensable for implementation of core technologies of Industry 4.0 in a smart manufacturing setup (Elbasani et al. 2020). In the past two decades, there have been many positive changes in the technological paradigms due to the immaculate developments which have revolutionized the world and influenced the lean manufacturing techniques for a better utilization and performance. Many manufacturers tend to utilize two different types of automated data collecting technologies; which are Bar Code technology and RFID technology. The implementation of RFID systems is very much attractive in many organizations such as industries and the educational institutes, as this technology provides enhanced information about many operations and the customers. Many researchers have opinion that it will bring a reform in the traditional supply chain (Jones et al. 2005). The introduction of RFID technology has brought a revolution in information and research, which is a testament to its positive results. Many organizations have started adopting this technology and applying it to their supply chain, and few are utilizing RFID tags for improving and simplifying their security systems.

In many comparisons with the bar code technology, the RFID has advantages and it eliminates the shortcomings of Bar Code technology such as the requirement for line

of sight and short range operations. Moreover, it carries more automated operations as compared to Bar Code technology, thus eliminating labor-intensive activity. Furthermore, RFID technology provides the ability of tracing the objects throughout the whole supply chain. The RFID tags are more proficient as compared to Bar Codes as there can be more information stored on RFID tags such as expiry dates, and these tags can be used repeatedly by rewriting the information on these tags. The RFID systems have very long rages such as 300ft and these systems are very fast in comparison to the conventional Bar Code systems. The level of security in RFID tags is very much improved than the Bar Codes and the items having RFID tags can be traced easily in few seconds in any warehouse. This aspect helps to reduce unnecessary inventory, and also helps eliminating any chance of theft and mistakes in a supply chain. Owing to these advantages, many traders and super markets are adopting RFID technology in their systems to avail these potential benefits.

Despite these major advantages of RFID technology, the Bar Code technology still carries few benefits in comparison, such as this is a very much handy and light weighted technology. In addition to that, the initial cost requirement of this technology is very low as compared to RFID technology. Moreover, the Bar Code technique is not very much dependent upon high technical support as opposed to the RFID technology. However, despite the limitations and the benefits of the aforementioned, both technologies find their use in different sectors; such as manufacturing, supply chain, production control and supermarkets. Nevertheless, in general comparison and in long-term benefits, the RFID technology is more beneficial. Furthermore, the successful implementation of RFID can be successfully achieved through TOE framework, as the organizational structure and context is taken into account, thereby complementing the adoption of new technology.

A great overlap has been observed between both technologies and as no study reviews the existing literature in this regard and in the terms of integration of better technology in context of TOE framework with Industry 4.0 concepts pertaining to automated data collection.

Rest of article is divided into various sections. Sections represents comprehensive literature review regarding both Bar Code and RFID technologies, methodology adopted. The further section represents systematic details and comparison among technologies. The last section also highlights the several essential elements for successful implementation of RFID technology in context of TOE framework.

LITERATURE REVIEW

BAR-CODE TECHNOLOGY

Mainly Bar Code technology can be clearly described as a line of spectacle technology (Rouse, 2009). This is called so because these technologies work on the visually represented data, which can be easily scanned by any suitable scanner, and the data is being read in the form of bar codes (Adaptalift, 2012). There are confidential codes in each bar code which are displayed in the form of lines with a sequence (Adaptalift, 2012). These codes are read by a scanner which is mainly a bar code reader having a laser light which is stimulated and flashes when the button of the scanner is being pressed by the user. Moreover this laser beam assists the user in reading the lights that are being reflected from the lines (Rouse, 2009). The reader also transforms the obtained data into digital form and sends it to the computer storage for immediate actions (Rouse, 2009). From last decade this bar code technology has become widespread in many retail stores and markets, and is also applicable to shipping management and in the manufacturing of the many products on industrial level (Boyer, 2001). In addition to that, bar code technology is used for the identification process of library books and also identifying the hospitalized patients (Rouse, 2009). There are many advantages and limitations of a bar code technology-based system which will be briefly described in the next sections.

RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY

Recently, many newer technologies have been invented, from these the RFID technology has become very popular in many fields of life such as academics and industries (Ju et al. 2008; Sarac et al. 2010). The most beneficial aspect of RFID technology is that it is very much faster than the conventionally adopted bar code technology. In addition to that, it is very much automated in a comparison with bar code method, and does not require manual assistance. The attached RFID tags can be easily read with the application of radio frequency, within a prescribed area and it doesn't create any interference with other system (ENASYS, 2014; INLOGIC, 2013; Muller-Seitz et al. 2009; Roberti, 2013; Vlachos, 2014). Tajima (2007) explained that the system based on RFID consists of microchip RFID tags which occasionally have antennas, along with electronic reader

(reads the information on the tags) and also a middleware, that summarizes and filters the information for avoiding any possible inaccuracies and also managing the operation. RFID has been claimed to be a system which is highly automatic (Vlachos, 2014), having many advantages and much better than conventional bar code technology of scanning. RFID systems consist of tagging systems, tags and reader which are frequency controlled. There are many types and ranges of these systems depending upon the price, the required manufacturing structure and prospective gains (Sarac et al. 2010). It has been observed that RFID systems are applicable in material handling applications and can be utilized in ordering required stock due to its precise demand predictions in line with the customer demands and requirements (Vlachos, 2014). RFID plays an important role in the Industry 4.0 (Evdokimov et al. 2011; Jia et al. 2012), improving supply chain inventory practices (Fan et al. 2015), logistics (Oliveira et al. 2015; Shi et al. 2011) and performance of manufacturing sectors (Liukkonen, 2015; Zhong et al. 2013). RFID is considered to play an effective contribution towards upcoming revolution of Industry 4.0 in manufacturing processes regarding production & quality optimization (Occhiuzzi et al. 2019).

METHODOLOGY

The authors have opted the literature review methodology for present study. Figure 1 illustrates the research methodology. Consideration criteria includes the most pertinent high impact journals, conference papers, books and inter-web data for period from 1990 to 2020. In order to find most relevant literature, Google Scholar search engine was mostly used to explore the databases. ScienceDirect, Springer, Nature, Scopus, Web of Science, Emerald, Journal Storage (JSTOR), Taylor & Francis (T&F) & Wiley etc. were also investigated.

To filter relevant data, several keywords like "TOE Framework, RFID Technology, Barcode Technology, RFID implementation, Technology Implementation in Production systems, Improving process visibility, Technology implementation in lean manufacturing systems, RFID and Industry 4.0" were used.

A large number of studies were collected from the above mentioned online databases. However later data was filtered out for relevancy, quality and consistency, Further sections as indicated in the introduction were compiled after careful analysis of filtered data to fulfill the core purpose of the present study.

This filtered studies or data was then thoroughly reviewed to produce required results.

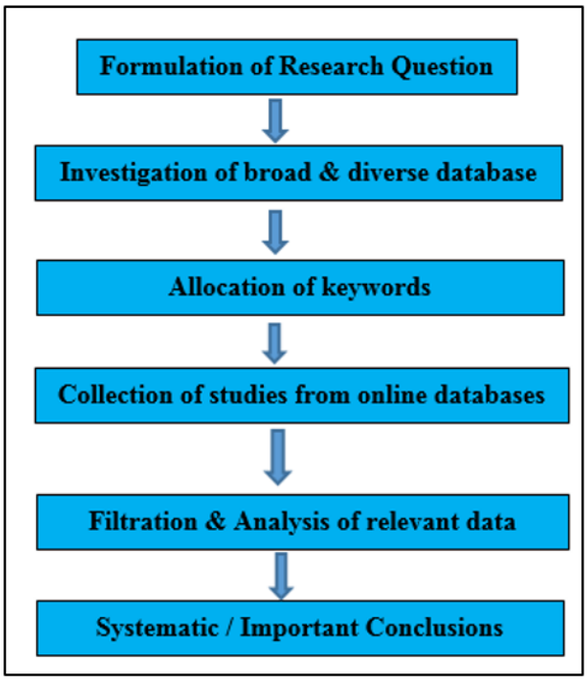

FIGURE 1. Research Methodology

RESULTS

MERITS AND DEMERITS OF BAR CODE TECHNOLOGY

Although the technology of bar code is an older one but still it has many benefits such as being lightweight, handy, convenient, low initial and maintenance costs, easy and economic printing. Furthermore, this provides almost same accuracy for various applications and there are no privacy issues related to this technology. However the limitations include the dependence upon the manual efforts due to being based on manual scanning, short scanning range, non-reusability and non-rewriteable bar code. The bar code lacks in many important aspects such as the expiry dates of any products, there is another disadvantage that the bar code can be easily forged and reproduced; thus it is not fully secure. Moreover, it can be easily damaged thus becoming unreadable (Adaptalift 2012).

The benefits and limitations summarized above show that this technology is not very much suitable for a smoother operation in large manufacturing setup , and to overcome these limitations there should be another fully automated technology, such as RFID (Adaptalift, 2012).

MERITS AND DEMERITS OF RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY

The RFID technology has many advantages over the bar code technology as its tags can be read effectively and quickly as compared to bar code. The range of readability of RFID is about 300 ft., which is much more than bar code technology. Also, no line of sight is required in RFID scanning, the tags of have ability of rewriting and re-readability, which is not possible in bar code. These tags are not just the tags, but are micro-chips in which data is saved and as there is an option of password protection, this method is much safer than bar code. After using the saved data from these tags the data can be easily deleted that is available in every chip. These tags have much more details such as expiry dates of a product and history of transfer. Also, the manual efforts are not required in RFID systems, once it has been activated. It has become omnipresent in industry and our daily life applications such as ticketing and payment, etc. (Duroc et al. 2018).

This technology also has few disadvantages as its initial cost is higher as compared to barcode technology. Also there remains the requirement of technical guidance for the initialization of this technology, for example inserting the tags. Rarely, there are possibilities of collisions whenever there is a huge number of tags are present. The implementation of RFID always requires some technical expertise.

COMPARISON AMONG TECHNOLOGIES

After reviewing thoroughly about the Bar Code and RFID technology as indicated in previous sections, a general comparison can be drawn between the capabilities for determining which is more suitable under which conditions. This provides a better understanding about the differences between these technologies, which is required to eradicate the confusing overlap.

The bar code technology depends upon the line of site whereas in RFID there is no requirement of it. The bar code technique is based on optical laser while RFID is based on radio frequency identification method. RFID has advantage of re-readable and rewriteable tags whereas bar code is written and read only once. The bar code systems have manual scanning while RFID systems have automatic scanning process. In bar code method only one bar code can be read at a time, while in RFID application multiple tags can be read at a time. The speed of bar code systems is very slower as compared to the RFID systems which are about 20 times faster than bar code technology. The bar code systems are very labor intensive and in RFID negligible labor force is required. The RFID tags can store data whereas in bar code it is not possible. However there are some benefits of bar code technology over RFID systems such as the initial cost is lower for bar code implementation. Bar code technique is simpler than RFID, and there is no much technical expertise required in bar code system as compared to RFID. Moreover RFID tags are installed inside the packages and bar code are pasted on outside and lastly the bar code is less expensive in comparison to the RFID systems costs (INLOGIC 2013).

This comparison has clear indications that under different scenarios, the RFID technology has far better capabilities than the bar code technology. On the basis of automation the major difference between these two techniques is that bar code technology is semi-automated as there is manual scanning is required for the bar codes, despite that the next step of data transfer is automatic, whereas the RFID is a fully automatic technology. Many researchers support the possible paybacks of RFID technology. As according to their point of view the data transfer via RFID and system of information is highly productive in the planning process, implementation, regulation and refining supply chain and manufacturing methods (Jimenez, Dauzère-Pérès, Feuillebois, & Pauly 2013; Ngai et al. 2010). Another advantage of RFID technology includes the higher control on the production, better response on customer orders, lowering the lead times, reducing the inventories and facilitating the workers during the working hours (Chongwatpol et al. 2013; Huang et al. 2010; Qu et al. 2013; So, 2010). RFID is also very much effective in reducing the problems faced in inventory management and also minimize the bullwhip effect by the help of its improved system having access to real-time information of organizations (Bottani et al. 2010; Kok et al. 2014). The overall profitability and system performance can be also improved by the implementation of RFID as it has ability of improving the availability and traceability of the product (Aiello et al. 2015; Gaukler, 2010). As there are the advantages of RFID technology there are disadvantages as well, such as high initial installation cost and requirement of expertise is noticeable, however if this technology is implemented by experts in the field and by selecting suitable tags, these initial limitations can be handled.

IMPLEMENTATION OF TECHNOLOGIES THROUGH TOE FRAMEWORK

In recent decades, with the innovative technologies, RFID is becoming the most promising and predictable technology. As a result there are many organizations planning to implement this reliable technology in their systems to improve their competitiveness. Due to novelty of this technology, a lot of capital investment and high technical

support is required for a successful operation and due to these challenges, there are many efforts that have been reported as a failure. However a successful implementation of RFID can lead to a lot of cost saving and market competitiveness for an organization. In this current work the potential benefits of RFID implementation are being considered, including the factors which may contribute the chances of a successful adoption of RFID in various organizations. Many researchers consider RFID technology as an initial step towards the wireless communication and also highlighted it as the best option to be combined with lean practices for achieving productive results. However to obtain considerable results, there must be a thorough study for a successful installation of RFID, as it has been observed in few cases that many organizations try to rush towards the implementation of many modern technologies such as RFID utilizations and mostly their efforts become fruitless, as the expected results are not achieved in many cases due to deficiencies like improper studies prior to the implementation of technology (Oliveira et al. 2011; Pool et al. 2015; Tornatzky et al. 1990; Wang et al. 2010). From many research articles, there is an observation that most reasonable and familiar technology implementation observation is Technology-Organization-Environment (TOE) framework (Tornatzky et al. 1990; Wang et al. 2010). For implementation of Radio Frequency Identification (RFID) technology, TOE framework has been considered as a foremost implementation approach, as in past it has been practiced several times (Gibbs et al. 2004; Kuan et al. 2001; Tornatzky et al. 1990; Wang et al. 2010; Zhang et al. 2007). Wang et al. (2010) in their work justified regarding the usual features that were spotted as an integral part of organization, technology and of environmental backgrounds aspects of a setup. The major aspects in environmental context are the accessibility of information and trading partners and competitor's pressure. Whereas in context of organization, the commitment level of management, competency level of technology and the size of the firm are the major and effective aspects. However, in the context of technology mainly the possibility of benefits, compatibility and complexity level are concerned. Consequently, it has been observed by the authors that nearly all these above mentioned aspects have their own relevance and significance in technological, in organizational level and in environmental contexts and it seems that these are applicable to be considered in this research case. From the previously available literature, it has been concluded that in the TOE context, out of these perspectives the most prominent and important are the visibility of information, commitment of management and suitability of technology, respectively (Jasti et al. 2015; Lee et al. 2007; Thong, 1999; Wang et al. 2010). Correspondingly, it is also has been observed that RFID technology commonly includes all above mentioned significant features along with it and thus it has been concluded as a finest system. However, this requires the true support and commitment by the management of an organization. In a gist, use of more complex decoding process in RFID yields a more robust system in different application scenarios (De Alencar et al. 2019).

CONTEXTS OF TOE FRAMEWORK

The implementation of RFID in any organization can assist to improve its competitiveness by influencing the organization in the context of technological-organizational-environmental framework. From the available literature it has been analysed that RFID along with its all features can be an optimum solution towards the future challenges and is contributing positively towards effective supply chain performance (Ali et al. 2019) . The most prominent contexts are briefly discussed in next sections.

TECHNOLOGY CONTEXT

Compatibility

The compatibility of the technology is an important element. Fundamentally, term compatibility can be described as the extent to which the modern technology has similarity to the older installed technology (Tornatzky et al. 1990). Many times there is an error reported that stakeholders try to install newer technology without considering whether it is compatible to the previously installed or not. The higher the compatibility, the higher will be facilitation for the newer technology induction (Thong, 1999). If the newer technology is incompatible with the previous, then there will be a totally new setup required, which traditionally involves higher expertise and finance requirement.

Complexity

Lower complexity level means that technology should be simpler and easy in usage. If technology is complex, than it will require much time for learning and its implementation in any system (Tornatzky et al. 1990; Wang et al. 2010).

Relevant advantage

The relevant benefit of technology means that there must be sufficient merits in the adaptation of newer technology. For example, it should be supportive, and valuable for meeting organizational goals (Bilgen et al. 2004; Chao et al. 2007; Ngai et al. 2008).

ORGANISATION CONTEXT

Management Commitment

The commitment by the management of any organization is considered as a central element towards the technology deployment. In a real sense, the commitment by the management is entirely responsible for the deploying and adapting the modern tool and technologies (Grover, 1993; Premkumar et al. 1999). The commitment by the top management, in the provision of support and vision, is an absolute requirement for attaining positive result and enhancing competitiveness (Lee et al. 2007).

Technology Competence

The second significant element/ factor is competency level of the technology, which means availability of IT specialist, having high level skills and experience in RFID installations and accessibility of infrastructure for achieving proper installation and functionality of said technology (Zhu et al. 2006; Zhu et al. 2003).Undoubtedly, the organizations having higher level of technological competency usually feel more confident to adopt or introduce such technologies in their systems.

Firm Size

In organizational context, the size of firm is considered as the third most significant factor (Damanpour, 1992; Grover, 1993; Premkumar et al. 1999; Tornatzky et al. 1990). There is a usual observation that if there is any organization which has bigger size, has much more assets and boldness to bear the changes of technology, the new ideas are taken up vigorously in such organizations. So this organizational component can never be ignored.Although there may be many fluctuations in the economic conditions, still there are requirements of capital investment for the adaptation of cutting-edge technology for successful sustainability in market.

Environmental Context

Information Visibility

Many researchers have justified that the first step for the environmental regime is considered to be the visibility of information. This element has been considered as the most crucial part in the context of the environment. Information intensity or visibility means the convenience of obtaining the information from the diverse operations of an organization and of any product, however it requires a strategic use of IT system (Chao et al. 2007; Thong, 1999; Wang et al. 2010). The main cause of the significance of this perspective in the TOE framework is that so many scholars such as, Jasti et al. (2015), Olesen et al. (2015) and Yap (1990) have clarified regarding the utilization of IT as crucial pillar of implementing lean practices in any production system and in supply chain structures. Thus this element has been considered as highly crucial element during the implementation of any newer techniques.

Competitor's pressure

Secondly the most significant element in the context of environment is "Competitor's pressure" means whenever the competitors start utilizing the modern tools and techniques for their products and operations, the organization is automatically pressurized to upgrade their tool and techniques to the latest one (Kuan et al. 2001; Zhu et al. 2003). It has been found from the observations that the pressure created by the competitors plays crucial role in the adaptation of newer technologies.

Trading partner's current Technology levels

Researchers have a narrative that the third important factor is the level of technology which is being utilized by the trading partners. Many studies have shown that whenever there is a pressure from the trading partners, it has sufficient impact on the up gradation of tools and technologies of many organizations (Gibbs et al. 2004; Iacovou et al. 1995). This is a natural trend that if both, the suppliers and the customers are utilizing the recent technologies, the organizations automatically desire to upgrade their installed systems to prove their stake as a professional partner and this automatically pushes them in the direction of technological improvements (To et al. 2006).

RFID provides long term benefits in the context of cost saving and improving many aspects of business such as improving supply chain, increasing information visibility and improving the competiveness of any organization. As it has proved itself as one of many techniques that are most promising and anticipated in recent decades and can be a valuable asset in lean practices; however there are still challenges such as integration of such technology to the already installed supply chain system due to the initial high cost requirements and the commitment of the management. Still, the potential benefits of this technology are very important and outweigh the disadvantages. There have been many efforts made for its implementation, although few have resulted in failure due to lack of experience and preparedness. The application of RFID in any organization can surely lead to improve control of production,

information, security and it has much more relevance in the organizational, technical and environmental context for any organization.

The study develops the systematic comparison between automated data collection technologies Different features of TOE framework provide a solid foundation to have integration of said technologies with Industry 4.0 concepts and to advance the production performance and overall supply chain management. The preceding literature and research works highlighted the prospect of the integration of RFID) with Industry 4.0 technologies; however, the present study supplements the range of contexts under the concept of TOE framework as well. This study develops that exertion and provides a comprehensive overview of the interaction between the RFID, TOE framework and Industry 4.0 concepts.

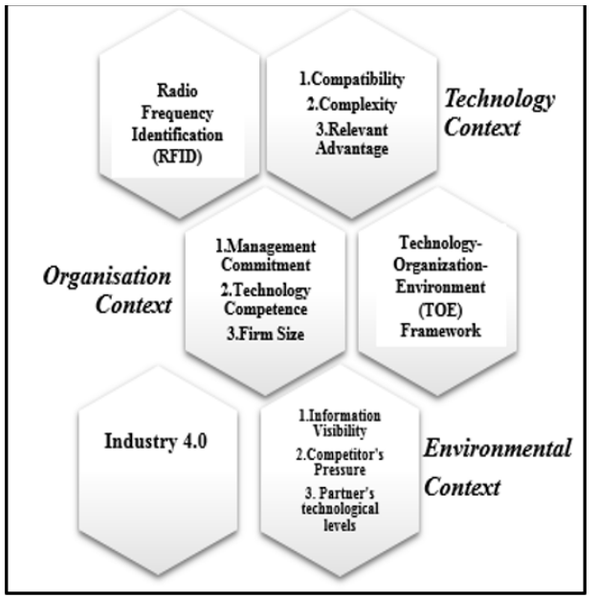

FIGURE 2. Contexts of TOE's Framework

CONCLUSION

This research work provides a detailed comparison between Bar Code and RFID technology in a holistic manner i.e. in their innate form as well as their applicability and implementation in various areas. Using Technology-Organization-Environment (TOE) Framework concept, the authors have described three different contexts and have concluded that RFID is a superior technology that provides more agile solutions. Moreover, RFID tags carry a larger amount of data in comparison to Bar Codes, thus aiding in inventory management and improving the supply chain performance. However, high initial capital costs and complex technical expertise requirement initially are a few issues that need to be considered. Nevertheless, the high reliability and agility of this system ensures smooth and error-free performance.

This research work will provide clarity to academicians and researchers regarding the applicability of RFID technology and its advantages over Bar Code based setups, since it allows a consolidated management system that entails objects as well as information. This results in highly reliable and hassle free communication. In managerial context, the research work describes the ease of implementation of RFID via TOE framework and highlighted the essential elements that shall eradicate issues such as inappropriate methods unsuited to environment, hindrance in multiple readings, miscommunication etc. Moreover, the application of RFID system reduces load on the system. The only drawback of high initial capital costs can be countered by considering RFID application as a long-term investment that culminates in highly reliable configuration of the system.

ACKNOWLEDGEMENT

The authors would like to thank to The University of Lahore and Universiti Kebangsaan Malaysia for supporting this research.

DECLARATION OF COMPETING INTEREST

None

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