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RFID Logistics Technology Solicitation in Oil Drilling in Saudi Arabia Energy Industry

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Abstract

Enterprises seek new ways to introduce tracking components into their products to solve logistical problems, and to gain an edge on the competition with user-friendly solutions. Radio frequency identification systems (RFID) technology enables automatic identification and localisation processing of objects by utilising radio frequency technology to wirelessly transfer data about the object to a computer. In this paper, the impact of RFID in Saudi's energy industry especially in oil drilling processes is investigated. Experimental research method was used to achieve its objectives. First, the nature of RFID technology in general and in Saudi Aramco is discussed. Subsequently, a Saudi oil company's activities are explored, highlighting a common issue the company shares with the oil drilling industry, that is, logistics in the supply of correct drill bits on site. Relevant RFID technology is then identified and its usefulness to the drilling industry now and in the future is explored. The logistics of implementing RFID technology is deliberated, as this requires a tiered or structured approach to allow for immediate benefits and future RFID applications.

***Keywords**: RFID Logistics technology; radio frequency identification; oil industry; energy exploration; drilling technology; Supply Chain Management; Saudi Aramco; Saudi Arabia*

Introduction

Radio frequency-based technology refers to remote identification and location of objects. An RFID system consists of a tag (transponder), a reader and a host computer. Prior to 2003, the RFID tags have only two components: an integrated circuit used for storing and processing information, and an antenna used for receiving and transmitting the signal [1][2]. The tags vary in complexity; passive tags are inexpensive with a low range, they are activated by the reader. Active tags, battery-powered, can transmit over longer distances [3] [4] [5]. The hybrid semi-passive tags utilise a battery to enhance the read range. All tags are programmable to change the type of data they collect and store. When energised, a RFID tag is either read or transmits its data to the reader, whereby this data or prepared information is transferred to a central computer, which may be integrated into a larger platform [4][5].

RFID technology's first application was in retail and warehousing to track high-end items and reduce theft, using radio frequency waves to uniquely identify a specific item. Now, uses include toll roads, banking activities and identifying livestock and pets [2][5][6].

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It frequently replaces barcode technology, as it does not require direct contact or line-of-sight scanning. The components are robust, and are less affected by harsh environment, water or dust. Whilst used mainly for security and logistics, RFID technology is a fast-growing field and the tags are capable of a range of activities based on data storage [1]. RFID components can also be synchronised with an enterprise's asset management system.

Even though low radio frequency (LF) band ranges from 30 KHz to 300 KHz, but LF at RFID systems operate between 125 KHz and 134.5 KHz [2][6][7]. On the other hand, high-frequency (HF) band ranges from 3 MHz to 30 MHz, but for most HF RFID systems works at 13.56 MHz. These systems have short transmission ranges (generally 0.1 to 2 meter). For ultra-high frequency (UHF) band ranges from 300 MHz to 2.5 GHz, but for RFID, UHF ranges from 860 MHz to 960 MHz and they offer longer transmission ranges (up to 100 m). The higher and microwave signals are attenuated and reflected by human tissue and moisture bearing objects and must be used with caution. Short wavelengths of radio signals and reflective properties of metal objects allow good performance in such environments [2]. These offer higher data rates than inductive systems and allow many systems to operate independently in confined operating areas, relevant to this case. Also, higher frequencies enable higher data transfer rates, although, as noted, these applications are more expensive [8].

The characteristics of the RFID system are the amount of data stored, the physical size of the tag, the read range, the ability of the system to communicate simultaneously with multiple tags and the speed of communication between the tag and the reader [9]. Passive RFID tags cost about US$0.10 each; however active RFID tags costs from US$15 to US$20 each and it can reach US$100 each; while for RFID readers cost between US$1,250 to US$20,000 each for handheld readers depending on the level of automation offered, Active RFID readers cost at US$1,250 to US$1,500 each, and passive and handheld RFID readers costs ranging from US$3,000 to US$20,000 each [6]. Table 1 summarises the differences between active and passive tags.

Table 1 - Active and passive RFID tags

	Active RFID	Passive RFID
Tag Battery	Yes	No
Availability of tag power	Continuous	Only within field of the reader
Required Signal strength from Reader to Tag	Low	High
Required Signal Strength from Tag to Reader	High	Low
Communication Range	Long range (from a few meters to 100 meters)	Short range (from a few centimeters to 5 meters)
Multi-Tag Collection	Can collect information from multiple tags moving at high speed	Limited multi-tag collection capability
Sensor Capability	Ability to continuously monitor and record data from sensors	Can collect and transfer data from sensors only when in range of a reader
Data Storage	Large read/write data storage with sophisticated data search and access capabilities available	Small read/write data storage
Frequency of Operation	Operate at higher frequencies:315-433MHz, 2.4 GHz, & 5.8 GHz	Operate at lower frequencies:125-134 KHz, 13.56 MHz, & 860-960 MHz

Source: [14].

1.1 RFID in Oil Drilling

Oil drilling is a difficult venture with high failure rates in extreme environments, long periods of intense work and short-term targets. Drilling companies require dependable supplies and good logistic support to fulfil their contractual obligations wherever they are drilling. Innovative companies around the world find that RFID can improve their business intelligence and streamline their safety, inspection and supply operations [10]. In 2007, the US oil and gas industry spent about $104 million on RFID solutions to improve logistics for their drilling operations [11]. Technology advances are extending the range of RFID applications:

- By embedding RFID tags along a drill string (sections of a drill pipe) depth can be measured, whilst monitoring the various sections of the string [12]
- Actuating self-powered downhole tools is a highly rewarding improvement in operating costs at the wellhead through less tool time in the hole, reduced number of trips and its multifunctional capabilities [13].
- After the well is drilled, a clean-up operation must be performed to assure the integrity of the well before running the completion. RFID tags or chips can be pumped through the hole for certain purposes [13].

1.2. Drilling and Workover Organisation

As noted, RFID technology is achieving increasingly innovative applications as its usage expands throughout the oil industry [16]. In this case, embedded tags in drill bits could be used simply to identify and locate individual parts. Industry uses, however, are now extending to using the technology in the well itself to activate equipment along the length of the pipe [9][16]. Whether this is feasible for Saudi Aramco at this time is a matter of determining the return on investment, and a business case is required for this purpose. RFID usage would reduce downtime and location costs and would significantly improve the productivity and reduce expenditure [17][18].

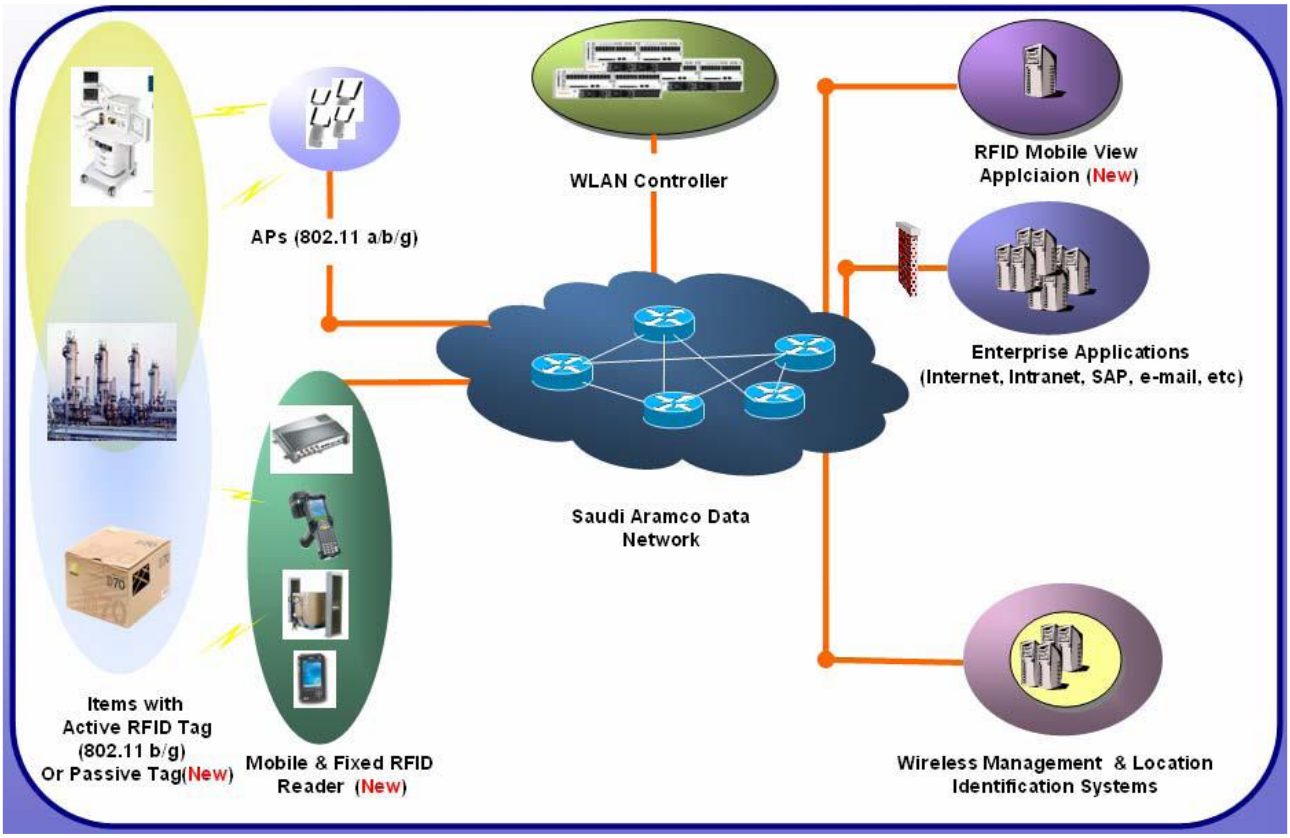
It is expected that, with a plan integrating the first stage of an RFID application into Saudi Aramco's SAP platform, a cost-benefit analysis can readily be made for RFID deployment for proper identification and supply of drill bits. When stakeholder approvals are obtained, the business case then sets out the planning and execution of the RFID project. This includes a decision on the type of vendor, full service or otherwise; selection of relevant firms, and the timeframe for the project up to a decade beyond commissioning. Further, in a rapidly developing ICT sector, all applications should be open to future change [19].

1.3. Drill bit RFID application

The oil and gas industry is experiencing volatile trading conditions and strong pressures to meet performance targets [18]. Drilling & Workover Organisation (D&WO) requires excellent logistics in supply, transport and storage of parts and consumables to service its many operations in the field. Moreover, the sophisticated nature of the drilling operation requires planning, ordering, and delivering only the good quality materials and equipment to avoid failure of components in the field. Whilst used drilling bits are used to cut costs, adding to the failure rate, there are frequent instances of wrong deliveries from Saudi Aramco's suppliers or an inexperienced drilling supervisor may use an inappropriate drilling bit. Inexperience and inattention to details, sometimes in onerous climatic conditions, causes delays and perhaps downtime until the correct bit is recovered. Thus, a system is required that would minimise failure rates and downtime by assuring that the correct bits are on hand. Using RFID tags could identify the bit and remove the element of human error from bit usage [17][20].

2. Method and Procedure

The method used in this study is the case experiment in Saudi Aramco Company. Saudi Aramco, the state-owned oil company of Saudi-Arabia, is one of the world's largest oil corporations in terms of proven crude oil reserves and production. A Saudi Aramco representative [15] explained the company's widening usage of RFID high level design for passive and active technologies as illustrated by figure 1.



Source: [15, p.22]

Figure 1 Saudi Aramco's application of RFID technology

Saudi Aramco's RFID design consists of middleware, passive RFID readers (mobile and fixed), passive and active tags at different frequencies. The RFID system can be established over the existing corporate network utilising the wireless network over SAP platforms that will assist in incorporating the RFID system integration [15].

2.1. Definition of project

The project is two-fold: first, a supply chain application is required to identify drill bits and locate them on site [18][21]. Before delivery, an active RFID tag is embedded in a position on the drill bit unlikely to experience damage. This allows better planning on site, where an engineer can identify the type of drill bit to be used based on expectation of strata conditions in the well. It also facilitates identification and the location of the tool. At a later stage, the information in the reader can also be transmitted to the Saudi Aramco Data Network to allow asset tracking, maintenance scheduling and replacement information. Full use of this first project is expected to decrease tool costs by at least 25 per cent and substantially reduce human error and thus recovery times.

The second, project is that the drill bit tag may be employed further in its tool actuation capacity. Whether tags are embedded in the drill bit or are otherwise introduced in the hole, the reader and networks require capacity for increased usage of tags as the technology improves and new applications come on stream.

2.2. Finance and costs

The costs for RFID applications are hardware, software and services. Hardware includes tags incorporating antennae, readers, network, and platform computers. Software costs comprise purchasing or writing the programs required, and installation on Aramco's SAP platform. Services include the cost of installing, tuning and integrating various components, training and maintenance [22].

An advantage of RFID for Aramco is the reduction of labour costs [18]. As an example, the use of an incorrect drill bit can cost up to 16 hours of additional time through running the wrong bit out of the hole and then re-running the correct bit to resume the drilling operation. In this instance, RFID technology could be used to identify the

correct bit in the first place, thus saving the entire episode in regards to time for the number of persons at the site. This application facilitates handling, transport to the site, and prevents the incident occurring [23].

RFID benefits are predicted to exceed the overall cost of the technology for this case. A cost-benefit analysis is critical to the successful deployment of the RFID project and this solution will be viable in its return over investment both for the short- and long-term productivity of the enterprise.

2.3. Provider

Whilst Saudi Aramco uses both in-house and contractor RFID expertise, in this case the technology is somewhat different, in embedding tags in drill bits, and taking this further into smart tag technology later. This requires a team approach, including IT platform contractors, RFID expertise, supply line staff and drillers to allow appropriate technology to be identified [20][22]. Once this occurs, an Aramco project management team can then be directed to undertake plan preparation, stakeholder management, approvals, finance, and oversee installation.

Once specified, providers are assessed. These may consist of technology, support services, installation, training or a combination of these from one or two firms, depending on the final decision as to the extent of the project [23]. For this project, a single provider is preferred due to the on-going nature of the project and that there are levels of integration and responsibility involved. One supplier defines these factors and this approach is accepted through the oil industry as there are at least three development installation firms capable of performing this work over the mid- to long-term. The provider should be capable of integrating the firm's technology with the various aspects of Saudi Aramco's ICT. This approach is selected based on the nature of the oil industry, and by analysing the business requirements, that is, using technology to improve asset management in logistics. This will result in better process management by reducing the risk of equipment failure, stand-downs and accidents due to using incorrect hardware [16][20][22][23].

After consultation and assessment, the submissions of three firms, Burran ICT Group, Zenith Outfitters Pty Ltd and Merrick Systems Inc. (now known as P2 Energy Solutions[1]) were found to meet the requirements of a single provider. All had met primary needs of supply, delivery and installation; however, they differed in the support they could offer.

Management Team. Experienced and knowledgeable management are required in this instance, due to Aramco's current growth and inability to recruit sufficient expertise in RFID applications. The contractor's management must have a track record in Saudi Arabia, or at least on the Arabian Peninsula, and an appropriate profile of disciplines. Further, the contractor must communicate with the Aramco project management team. Of the recent providers for RFID technology in the corporation, the management team from Merrick Systems was well recommended.

Sub-contractors. In the next step, the Aramco team considered partners and alliances that are well known and are willing to be referenced. A vendor's relationship with its partners and alliances highlight the track record, experience, and credibility of the company. Merrick Systems partners include Arcadian Networks, NuTech Solutions and RFID Inc. Burran ICT Group also shared NuTech Solutions and RFID, with iiCT. Both these were equally acceptable; however, Zenith partners were not able to provide similar support at this time.

Experience. The contractor's reputation in the oil industry has a crucial role in determining its track record of quality work delivered on time and on budget. All applicants' client list contained the oil drilling industry, including Devon Energy, EOG Resources, BP and Anadarka Petroleum. Merricks provided the most notable clients, had a solid IT architecture design history, and thorough RFID-specific technology experience. In this respect, Merricks was the superior provider.

Quality standards. Addressing quality standards in this harsh climate is the key to a successful project. Whilst Saudi Aramco acknowledges that there are issues in the logistic of sourcing and delivering equipment and parts to the remote wells, the contractor is required to maintain appropriate standards at all times. All firms have a proven record in International Standards Organisation (ISO) compliance. Further, Merricks developed a drill bit tag in 2008 to meet the ISO 18000-2:2004 standard (Information technology -- Radio frequency identification for item management - Part 2: Parameters for air interface communications below 135 kHz).

Summary. Merrick Systems was chosen on the above criteria, despite superior performance in Zenith's communications and training team. The selected firm will address this issue to the satisfaction of the assessment team before the contract is presented to Saudi Aramco for negotiations regarding security, legal and financial arrangements.

2.4. Technology

The technology chosen for this RFID application is Merrick's RFID tracking system to provide real time asset tracking. The process uses the elements of passive RFID

[1]P2 Energy Solutions acquired Merrick Systems Inc. in November 2014. News accessible via: https://www.p2energysolutions.com/news/p2-energy-solutions-to-acquire-merrick-systems [Last viewed on 7 October 2019]

tags, readers and the recording and analytic software: RFID tags, Rig-Hand, and Corporate Asset Tracking System (CATS), respectively. These are explained below.

RFID Tag. RFID tags can be resistant from temperature at minus 40^0C to plus 120^0C, chemical reactions, and can be used on metal or any substantial surface [24]. This meets the criteria for oil drilling. Merrick RFID tags are surfaced with a high resistance polymer, and are the size and shape of a small coin. They are inserted into the drill bit in locations where they are less expected to be damaged. The RFID tags are 125 kHz passive chip compliant with ISO 18000-2 standard. This range provides good reading capability without interference from extremely metallic atmospheres and can read through chemicals used in the drilling process [16][18][23].

Rig–hand. Rig-hand is a wireless, mobile device the size of a BlackBerry that reads the tag data and stores information regarding the drill bits. The Rig–hand stores information on the drill bit usage [25].

CATS. The corporate asset tracking system (CATS) software system stores data from Rig-hand and provides analyses as required. CATS can be integrated into Saudi Aramco's management systems [18]. Further, CATS can automatically alert relevant supervisors regarding performance extremes to initiate an inspection of the drill bits.

Integration. The passive RFID tags on drill bits send bit identification information to the on-site Rig-hands which store the information Aramco requires on its drill bits, including the time in the well and its environment in the well [18]. This data will be synchronised with CATS for further analysis and integrated with Aramco's asset management systems to assess efficient usage of the asset. CATS will be incorporated with Aramco's Supply Chain Management System for automatic ordering of drill bits through Electronic Data Interchange when bits require replacement.

3. Results and discussion

3.1. Implementation

Implementation of RFID must be done in a holistic manner if the efficiencies and controls the technology offers are to be truly realised' [18][26]. [22] modelled a holistic strategy for implementation of an RFID deployment framework as a series of steps, discussed below.

Business Problem. The business problem for Saudi Aramco in this case is the lack of a systematic tagging system for drill bits [18]. At present the tagging is undertaken by traditional methods or on-site decisions. This business assessment identifies Merrick Solutions' RFID technology as the most efficient and effective means to implement a supply chain function to alleviate the problem; it also has the capacity for analysis of the drill bits environment in the well. After acceptance by the stakeholders, the project implementation comprises a phased roll-out based on milestones, and these are aspects of a work break-down structure, the last section of which is a sustain and improve program. This later section will consider future benefits and opportunities to further develop this RFID technology.

Work breakdown. The systematic implementation of this technology can be performed on the basis of a work breakdown structure which distributes the implementation process in different subsections and schedules dates for task and project completion within these subsections as shown in Table 2.

Table 2 - Work breakdown structure

1.	**Project initialisation**
	Approval of the project and project meeting
	Team formation and work allocation
2.	**Placement of order**
	Computer equipment
	RFID Tags and Rig-hand
	Applications and software
3.	**Network cabling**
	Laying down the network cable
4.	**In-house assessment of CATS software**
	Configuring the CATS application according to requirements
	Case simulation
5.	**Assembling and installing of terminal equipment**
	Installing PCs
	Installing operating systems
	Installing software applications
6.	**Installing the RFID readers**
	Configuring RFID readers and Rig-hand
	Synchronising the application server with handheld devices
7.	**Transfer existing data**
8.	**Training**
	Training for the CATS Application
	Training for database management
	Training for Rig-hand
9.	**Testing user competency**
10.	**Project completion**

3.2. Training and Evaluation

Training is a crucial step in implementing this technology; it is regarded as a change management process due to the supply chain aspects, with the logistics of transport, storage and reuse of drill bits [18][23]. For IT group, there is the deployment of an additional management system which must be incorporated into their existing functions [16][22]. Field management require training in the new information at hand and in its efficient usage; and

operators required a thorough understanding of the technology and the responses required to enable the entire project to be successful. Training is, therefore, multi-level and multi-disciplined [16]. As the contractor, Merricks is aware of this factor and has arranged sufficient awareness programs, hands-on training, workshops and staff assistance to ensure the viability of the project. Turnover of staff is also an issue, so that Merricks will incorporate their training into initiation process for new staff.

Training sessions and interactive workshops will be provided for the supervisors and managers to understand the operation and advantages of the new system; they will be provided with training materials to assist them to train on-site employees.

An evaluation process will be undertaken every month to measure the improvement in drill bit usage by comparing error instances before and after full implementation. Employees will be regularly tested to determine user competency of the system [16][18][22].

3.3. Analysis of RFID implementation

The following analysis lists the benefits and challenges for D&WO in implementing RFID technology in regard to drill bits.

Advantages

There are immediate advantages and future opportunities in the use of RFID technology, as follows:

- Wireless data transfer provides immediate information availability
- RFID tags allow tracking under harsh conditions
- RFID data input functions include dimensions, material specification, purchases and use history and component inspections. The system automatically notifies which drill bits are due for inspection, thereby reducing the risk of catastrophic equipment failure
- Minimises human error and reduces overall safety risks and lost-time incidents
- Lowers asset costs through reduced maintenance costs, reduced downtime, lower operational asset failure, and cost effective solution to track operational assets
- RFID tags can track drill bits in the well whilst drilling, and keep track of logging tools' location.

Challenges and risks- Challenges and risks for RFID deployment in are economic, technical and implementation. These factors need to be examined carefully to develop a successful migration strategy [16].

Economic challenges – the hardware and software costs involved in setting up a RFID solution are high. But with the growing demand for RFID tags the costs are expected to go down over the years [16][18].

Technical challenges – RFID technology in the oil industry is still relatively new; high temperature RFID tags necessary for drilling are still in the early stages of development and there is a small risk in subjecting the technology to the extreme environmental conditions of deep well drilling [16][18][23].

Implementation challenges – RFID implementation can be complex since it interfaces with many intra-organisational sections and external contractors through the supply chain. Further, the RFID generates copious data for the drill bit applications which need to be synchronised with other asset management systems. Thus the company needs to assess their existing infrastructure and assess its ability to integrate the RFID technology and also ability to accommodate future technology evolution [16][18][23].

Employees and contractors require thorough training to gain the benefits of the technology. Whilst human error from the existing practices should reduce considerably, inattention and misunderstandings of the RFID system, particularly involving new staff, can undermine many of the potential benefits of the project [16][22].

4. Conclusion

RFID is rapidly changing the way enterprises operate in today's competitive environment. This technology can reduce expenses, increase revenue and drive competitive advantage if implemented in the correct manner. Deployment of RFID requires a business case including a cost benefit analysis to weigh its potential benefits to the organisation. Selecting the provider, implementing the right technology and integrating the new systems in to the organisation's policies and practices are important factors to the success of the project. Thus to gain maximum benefit from RFID technology, an organisation should undertake a needs analysis and prepare a strong future case for this emerging technology.

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References

[1] Petrariu AI, Lavric A, Coca E (2018) Design of an high frequency RFID multi-loop antenna for applications in metallic environments. *Advances in Electrical and Computer Engineering, 18*(2) 35-40

[2] Gonzales GZ (2013) *Radio Frequency Identification (RFID) Tags Reader Antennas Based on Conjugate matching and Metamaterial Concepts*. Ph.D Thesis, Universitat Autonoma de Barcelona, Spain.

[3] Zaid J, Abdulhadi AE, Denidni TA (2019) Miniaturized multi-port microstrip patch antenna using metamaterial for passive UHF RFID-tag sensor applications. *Sensors (Switzerland)*, Vol. 19(9) article number 1982.

[4] Ferdik M, Saxl G, Jesacher E, Ussmueller T (2019) Remote control system for battery-assisted devices with 16 nW standby consumption. *Sensors (Switzerland),* 19(4), 975

[5] Karmakar NC (2010). *Handbook of Smart Antennas for RFID Systems*. New Jersey: John Wiley and Sons.

[6] Advance Mobile Group (2019) *The Shocking Price of RFID Tags*. Viewed on 26 September 2019 at: <https://www.advancedmobilegroup.com/blog/the-true-price-of-rfid-tags.>

[7] Ciudad D, Cobos Arribas P, Sanchez P, Aroca C (2010) RFID in Metal Environments: An Overview on Low (LF) and Ultra-Low (ULF) Frequency Systems. In (Ed. Cristina Turcu), *Radio Frequency Identification Fundamentals and Applications: Design Methods and Solutions*, February 2010, INTECH, Croatia. ISBN 978-953-7619-72-5

[8] Clarke RN (2014) Expanding mobile wireless capacity: The challenges presented by technology and economics. *Telecommunications Policy, 38*(8-9), 693-708.

[9] Gupta V (2005) *Blending oil with RFID*, Wipro Technologies. Viewed on 7 October 2019 at < http://www.oilit.com/papers/wipro.pdf >

[10] Wyld DC (2009) The smart pipe: RFID and the oil and gas industry. *International Journal of Oil, Gas and Coal Technology, 2*(3), 201 - 214

[11] White J (2019) Refining the process: RFID is a growing force for profit, efficiency in the oil and gas industry, *IndustryWeek*, (2008, 2 September). Viewed on 26 September 2019 at: https://www.industryweek.com/companies-amp-executives/refining-process-rfid-growing-force-profit-efficiency-oil-and-gas-industry

[12] Swedberg C (2019) Tough RFID tag strikes oil. *RFID Journal*, (2008, 23 May). Viewed on 26 September 2019 at < https://www.rfidjournal.com/articles/view?4095>

[13] Snider P, Fraley K (2007) Marathon, partners adapt RFID technology for downhole drilling, completion applications, *Drilling Contractor, March/April 2007*, 40-42

[14] Amanna A, Agrawal A, Manteghi M (2010) Active RFID for Enhanced Railway Operations. *Proceedings of the ASME 2010 Rail Transport Division Fall Conference* (RTDF 2010), October 12-13, 2010, Roanoke, USA

[15] Al-Muhamed MS (2008) Radio Frequency Identification (RFID) for Automating Business Processes. *Proceeding of the Third eServices Symposium: The Future of eServices: The Next Step?* Khubar 26-27 February, 2008, pp. 13-23.

[16] Felemban A, Sheikh AA (2013) RFID for Oil and Gas Industry: Applications and Challenges. *International Journal of Engineering and Innovative Technology, 3*(5), 80-85.

[17] Sardroud JM (2012) Influence of RFID technology on automated management of construction materials and components. *Scientia Iranica, 19*(3), 381-392.

[18] Abosuliman SS (2018) RFID Technology In The Oil Industry "Feasibility Study".*Journal of Research in Humanities and Social Science, 6*(8), 12-16.

[19] Xu LD, Xu EL, Li L (2018) Industry 4.0: state of the art and future trends. *International Journal of Production Research, 56*(8), 2941-2962

[20] Kaur M, et al. (2011) RFID Technology Principles, Advantages, Limitations & Its Applications. *International Journal of Computer and Electrical Engineering, 3*(1), 1793-8163

[21] Schröder J, Warwas M (2018) *Successful Digital Product identification*. Master Thesis, KTH Royal Institute of Technology, School of Industrial Engineering and Management, Stockholm, Sweden.

[22] Manish B, Shahram M (2005) *RFID field guide: deploying radio frequency identification systems*, Prentice Hall PTR, Upper Saddle River, NJ.

[23] Grinrod M, Vonlanten M, Haaland AT, Gaaso R (2013) 'RFID. A Key Enabler in Drilling Automation'. SPE/IADC Drilling Conference, 5-7 March, Amsterdam, The Netherlands. (2013). Society of Petroleum Engineers.

[24] Abanob Abdelnour (2018) Development of UHF RFID tags for traceability and quality control of food products, Application: Cheese production. Optics / Photonic. Université Grenoble Alpes, 2018. English. ffNNT : 2018GREAT081ff. fftel-02092431. Viewed on 18 November 2019 at < https://tel.archives-ouvertes.fr/tel-02092431/document/>

[25] de Wardt JP and Rogers J (2011) 'Drilling Systems Automation - A Technology That is at a Tipping Point'. *International Petroleum Technology Conference*, 15-17 November, Bangkok, Thailand. (2011). Viewed on 18 November 2019 at < https://www.onepetro.org/conference-paper/IPTC-14717-MS/>

[26] Kleefeld E (2005) 'RFID expert says piecemeal approach won't work'. WTN News. (2005). Viewed on 7 October 2019 at< https://wtnnews.com/2005/08/15/2122/>