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Article

Application of Nano-Satellites constellation in the refinery mega projects implementation

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Abstract: The purpose of this article is to provide scalable solutions based on new technologies in the field of refinery mega projects. Correcting defective structures and providing a new model and mechanism for completing projects in comprehensive and optimal manner may be conducted in terms of time, cost and quality of implementation. To this end, 156 effective factors in delaying Engineering Procurement and Construction (EPC) projects using field research are identified. Then, based on the knowledge and experience of the project managers and experts in each field, and analyzing their views using Analytical Hierarchy Process (AHP) method, the most effective factors in project deferrals are identified. Also, the main factors of excess costs in EPC are extracted. According to surveys, lake of the following factors lead to project deferrals: real-time communication, integrated information network platform, common and up-to-date databases, online status equipment and sensors, and up-to-date information and regular reports. In many cases, these delays and corresponding surplus costs are so high that they compromise the economic justification of the project in terms of inflation. To solve these problems, the proposed method captures the required information from each refinery segment using sensors and Radio Frequency Identification (RFID) tags mounted on the units and areas and client computers deployed in each refinery segment using Internet of Things (IoT) technology. The information is then transferred to central sites and data centers via Nano-satellite platforms. The received information is classified into databases and processed by software packages such as Enterprise Resource Planning (ERP) and finally are made accessible for other units. The study also includes the validation of Nano-satellite communications as the core of the proposed solution using Satellite Tool Kit (STK) software. Then the information is processed by business intelligence techniques and the required consultations are provided at three strategic levels: 1) for senior holding managers for decision making at tactical level, 2) for mid-level managers, and 3) at operational level for workshop managers to make the right decision at the right time. Achievements of implementing this solution includes systematic project execution, characterization of project components and executing company processes from start to the end while minimizing the project time and overhead costs, and selecting the best vendors and materials.

Keywords: Nano Satellite systems; communication and information processing; refinery; power plant; project management; internet of things

1. Introduction

Given the mega scale of oil refinery and power plant projects in terms of workloads, finances, manpower and etc., providing comprehensive solutions and optimizing processes in this area has always been an important challenge to small and large employers and contractors to improve project quality and reduce project execution costs [1,2].

The high volume of project costs, the number of specialist Human Recourse (HR), expensive materials, scale and scope of work and geographic scope of work, puts the project at high risk of long delays, worries about return on investment for Employers, macro-level contractors and small contractors. One of the major issues in such projects is the delay in implementation of different parts of the project, which incurs significant costs for those involved in the mega-projects. The costs related to project delay may be categorized in three main groups [3–5]:

A) Quantitative costs including losses due to delay in gaining profits, costs of consumable resources (materials, etc.), also costs due to every-year-increasing salary of labour resources, and costs related to interest expenses

B) Qualitative costs including disadvantages due to losing market competition in the lag time, and costs due to loss of company credit. And finally,

C) The disadvantage of lowering government revenues and as a result the level of social welfare.

In recent studies, 156 factors were identified as the main causes of delays in EPC projects. These factors can be categorized in different groups, including 31 factors from engineering phase, 43 factors from procurement, and 82 factors from construction phase [3–5]. Among these factors 10 engineering factors, 16 procurement and 23 manufacturing factors (49 in total) were identified as the most influential ones [4–9].

Some of the causes of project delays and the main reasons behind them are listed in the following [3–5,10–14]:

1) Lack of specialist and qualified personnel.

Reason: Lack of a comprehensive database of expert personnel and their resumes.

2) Delayed engineering (consultant) response to changes in plans during project implementation.

Reason: Having faulty processes, and lack of comprehensive software packages such as Enterprise Resource Planning software (ERPs), integrated and accessible communications to complete the work cycle for contractors and consultants.

3) Delays in shipping and handling by suppliers.

Reason: Lack of comprehensive software such as ERPs to inform workflow, integrated communications and lack of online tracking mechanism such as RFID tags.

4) The unpredictability of the inflation rate and the increase in the cost of materials over time when project costs are presented.

Reason: Lack of information on project components and coherent mechanisms such as “Business Intelligence” (BI) for regular consultation and decision making.

5) Providing materials of poor quality.

Reason: Not having a list of vendors and technical specifications of their goods and their geographical location for database entry, processing and decision making.

6) Unrealistic (low) bidding when the contractor is bidding for the sole purpose of winning the bid.

Reason: Lack of information on project components and coherent mechanisms such as business intelligence processes for analyzing data and presenting actionable information which helps executives and managers.

7) Delay in tracking and solving raised problems (in and out of organization) by employer project managers.

Reason: Lack of process-driven software to execute a project from start to the end, such as ERP and data entry into databases to provide the necessary warnings before problems occur or to make decisions to solve problems based on BI.

8) Irregular payment of wages to second-hand employees and contractors by the general contractor

Reason: Lack of required software for comprehensive financial processing and providing high level financial advice.

It is clear from the above analysis that a key to resolve almost all of the above issues is a systematic approach to provide real-time access to required information that fully covers the refinery projects, workshops, headquarters, and key decision centers at any time and in every location.

Considering the vast geographic distribution of the national and international refinery mega projects and their huge amount of information, traditional methods of communications and transfer and process of data are not sufficient. Therefore, in this study, satellite telecommunication and other novel technologies such as RFID and IoT technologies are considered as solutions to address this requirement.

The novelty and scientific contributions of this paper, particularly in the proposed methodology, can be categorized into three main aspects: first, the integration and utilization of state-of-the-art technologies such as satellite constellations, the Internet of Things, and terrestrial and space-based communication transceivers; second, the reduction of human resource costs and execution time for mega-scale refinery projects; and third, the potential for generalization and adaptation of the approach to managing other industrial projects.

2. Nano-Satellites RFID and IoT technologies

The first satellite was launched in 1957 by the Union of Soviet Socialist Republics (USSR), and in less than a few months, the first Nano-satellite weighing about 10 kg was launched by the United States.

Later in year 1986, 25 small satellites were launched by the USSR, 24 of those Nano-satellites were placed in a constellation. After the year 1986, we were witness of many other space events, such as the launch of the Voyager 2 spacecraft and the launch of the Mir space station, which triggered the expansion of space science [15–17].

The program of Nano-satellites has been heavily on the agenda of universities, organizations and companies since 1999 and has significantly grown to date.

Figure 1 shows the number of satellites launched between 1995 and 2010 [18].

In the past few years much of the attention of the space industry has shifted towards the development of small satellites. This kind of satellite offer many potential benefits over traditional space satellites. Traditional space satellites are typified by geostationary communications satellites, which range in mass from 500 to 7000 kg. The development of this family of satellites requires millions of dollars and also five to ten years in terms of time. As a result, very little room exists for innovation and such satellites are often limited to the use of space-proven, though often outdated, technologies [19].

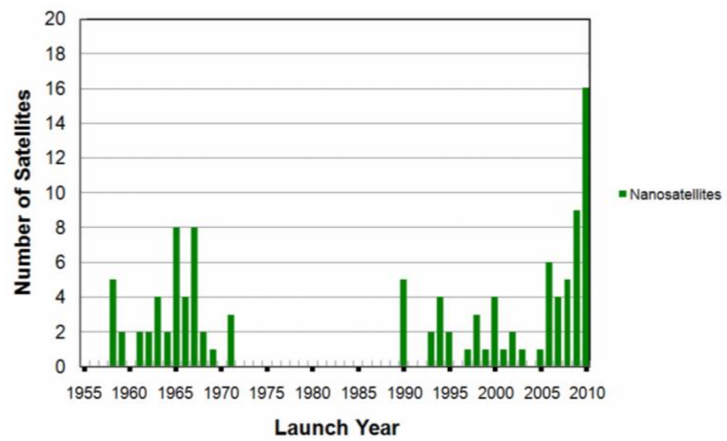


Figure 1. Graph chart of the number of Nano-Satellites per year [18].

In contrast small satellites provide an amazing alternative to traditional space satellites. Such projects are driven by a "smaller, faster, better, cheaper, smarter" mentality which allows for a fully functioning space satellite to be built in a fraction of the time and cost of a traditional space satellite. One of the driving philosophies of small satellite design is the use of standard, easy to use, Commercial Off-The-Shelf (COTS) components designed for non-space applications. This allows for fast and inexpensive construction, and reducing satellite complexity. The use of standardized platforms and reusable components further shortens the development process [20].

Considering these advantages, the development and deployment of Nano-satellite constellations to monitor the Earth in various areas, including oil refineries is pursuing by many countries. [21–24].

Today, many oil-rich countries or major contractors in the field are also looking for novel technologies to monitor the oil infrastructures and their related issues such as leakage of oil pipeline. Novel sensors, RFID tags and IoT are advanced technologies that can be integrated with Nano-satellite platforms to perform this task [25,26].

3. The proposed methodology

In the previous section, the main reasons behind delays in mega projects were identified and briefly described. The aim of this section is to propose a solution to address the main causes of the project deferral and mitigate their adverse effects. The proposed solution is based on real-time satellite-based communications, project communications, and real-time accessible headquarters [27].

The step-by-step procedure of the proposed method is shown in the block diagram of **Figure 2**. Also, an overview of the proposed solution is illustrated in **Figure 3**. As shown in the figure, the first step involves the collection of all relevant data such as information from sensors and RFID tags and also information from the client computers. Then a Nano-satellite constellation is used for the real-time transfer of the collected information to the core data centers of the organization, where the information is recorded and categorized in a central database. At this stage dedicated ERP and business intelligence software packages are used for real-time process of the information and to provide the required consultation for each section of the mega project, for instance on the best manner of the implementation processes, avoiding waste of time, identifying the goods needed, and information on the nearest vendor to get the high-quality goods and services in the least possible time. The system may provide a huge pile of useful information for each sector, for instance advice on the best way for the circulation of the current human resources and also on lists of possible highly specialized employees for each sub-project.

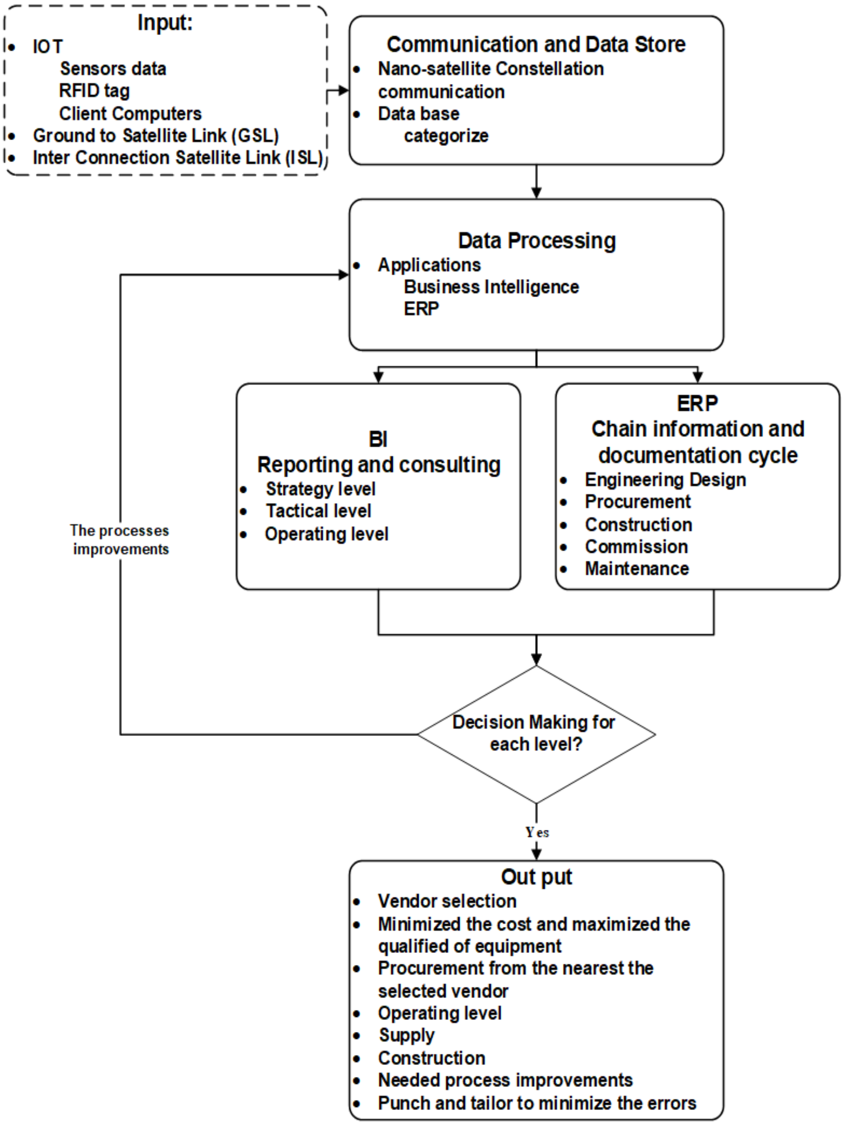


Figure 2. The proposed method algorithm.

The proposed solution also connects all the companies involved in the project by providing real-time information on all aspects of their project including the required materials and goods, human resources, main products and by-products, etc.

In the following, building blocks of the proposed method are briefly described.

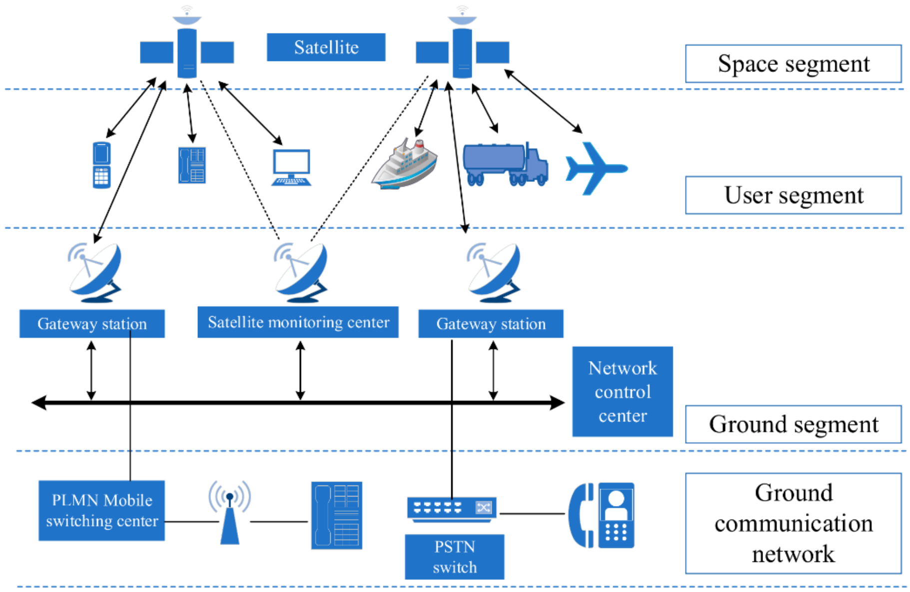


Figure 3. An overview of the proposed solution [28].

3.1. IoT (internet of things)

The IoT (Internet of Things (IoT)), which can be seen as the next evolution of the Internet, is a network of physical objects embedded with electronic components, software, sensors and connectors, so that they can provide value and services by sharing information with manufacturers, operators, or other devices. In fact, the overall idea of IoT is to receive, store, and send information from the environment to analyze it and ultimately provide smart services to the end user [29–31].

Nowadays, due to the widespread use of Nano-satellite technology with benefits such as much lower deployment costs, high coverage, avoiding terrestrial communication problems and proper bandwidth, Nano-satellite constellations can be considered as one of the main infrastructures for the realization of global IoT [32]. Such IoT system along with smart sensors and RFID tags enables users to have real-time access to all the required information from any location, at any time.

3.1.1. Sensors

Sensors that can convert values such as temperature, humidity, pressure, etc. into analog or digital quantities are one of the most widely used industrial automation equipments [33,34]. Examples of the installed sensors can be seen in **Figure 4**.

As shown in **Figure 5**, the sensors are not only used for the measurement of the physical parameters such as temperature and pressure, they are also used for the accuracy assessment of devices and machinery or for automatic request for required services.

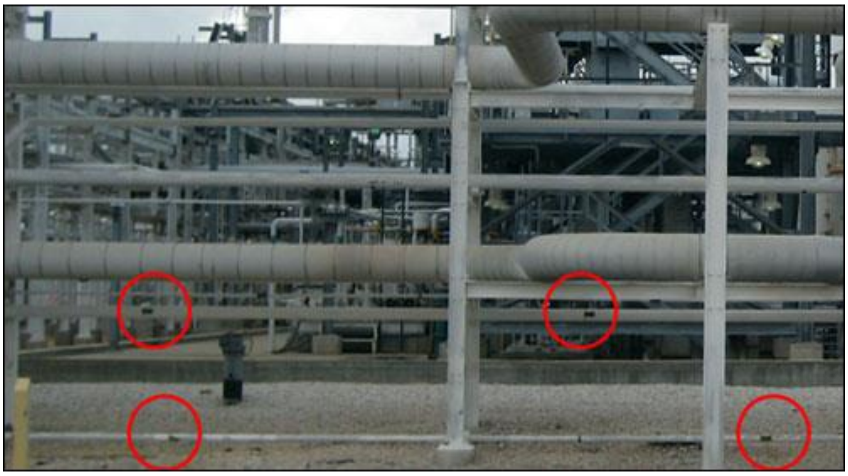


Figure 4. An example of a sensors and RFID installed in a refinery [34].

Figure 5. An example of sensors installed on equipment [35].

3.1.2. RFID

RFID devices are small electronic devices that usually include a very small chip and an antenna. These devices create a single attribute for each object that will be identifiable from other objects and are usually capable of carrying up to about 2000 bytes of data. RFIDs are widely used for tracking the resources used in different parts of a project. Therefore, they can be used to prevent waste of time in inventory control, also to prevent equipment theft, reduction of surplus costs associated to inspections and shipping [36].

In a traditional project management, the technical managers of each area or unit have to collect and enter all the information related to that section, for instance the percentage of work progress, amount of utilized material, amount of utilized human resources, etc. In modern approach RFID technology is used to automatically collect all this information. The collected data are then sent (via Nano-satellites) to the central site to be processed and shared with other units [37].

3.1.3. Clients

Network-connected clients are used to record, send, and receive information over the network. Users in refineries and headquarters are usually divided into two main categories as shown in **Figures 6** and **7**.

Office-based users who handle both administrative and technical information exchange tasks, such as (office automation users, specialized, engineering and finance software's), and mobility users who get report mostly from different parts of the organization and project or completing updating information on different parts of the project [38,39].

Figure 6. The shape of mobility user in refinery [38].

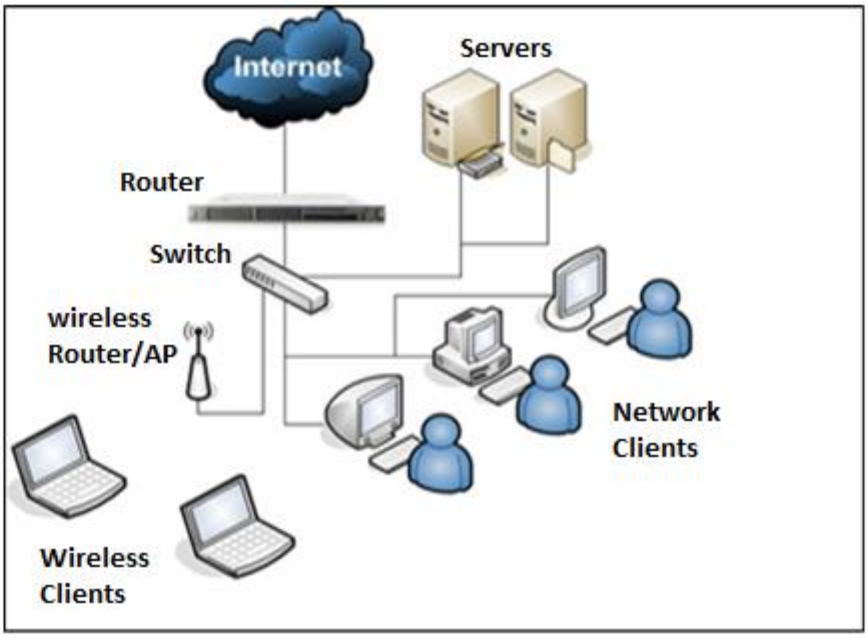


Figure 7. The shape of Network-connected client in office [39].

3.2. Databases

After collecting the information by tags, sensors and clients, the information is sent to the nano-satellites via links and this information is recorded and categorized in the databases located in the central data centers. So the database is a repository of extensive project-level information. The availability of this information source is very important in project execution, usually covered by disaster recovery solutions [40–42].

3.3. Nano-Satellites

In this solution, nano-satellites play a key role in communicating with all project components with headquarters, as well as providing a seamless platform for transferring or accessing real-time information from one endpoint to another endpoint. Some of the important features of Nano-satellites are [43]:

- Wide geographical coverage
- Low cost communication compared to terrestrial communication systems
- Wide bandwidth
- High reliability
- Ability to provide a variety of services required by customers
- Broadcasting
- Ability to support mobile users

3.4. ERP

In many buusinesses integrated and real-time management of the main business processes mediated by software and technology is required.

This is where ERP software paghages, which integrate the organization's internal processes and establish process relationships with external suppliers, customers and stakeholders play a critical role. These information systems are customized, integrated and developed to suit various requirements of the organization and the processes required through Beats Per Minute (BPM) tools and systems [43,44].

3.5. Business Intelligence (BI)

Business Intelligence provides critical information to senior executives with the process of large volumes of central database information, to provide reports and consulting, which are effective in competitiveness, risk management and assurance and in making effective decisions at the right time [45,46].

Business intelligence consulting is categorized into three levels:

A. Strategic level: that includes consultations on large-scale organization decisions made by senior managers and typically the organization's main orientations towards project acquisition, financial planning, engagement with co-operating companies, or alternatively competing with other companies and the organization's long-term plans.

B. Tactical level: that deals with the level of operational advice that is given to middle managers. These operations can include tracking down operations, how each company performs its tasks, reporting and ultimately gathering useful data for mid-term decision making.

C. Operational level: that is related to the lowest level of doing business in a company that is performed frequently and often repeatedly in the lower levels of the organization. This level of consultancy is generally used at workshops level and in the implementation of construction or in project modifications [44,46].

Figure 8 shows an overview of the business intelligence process of information querying, classification, information analysis and decision making.

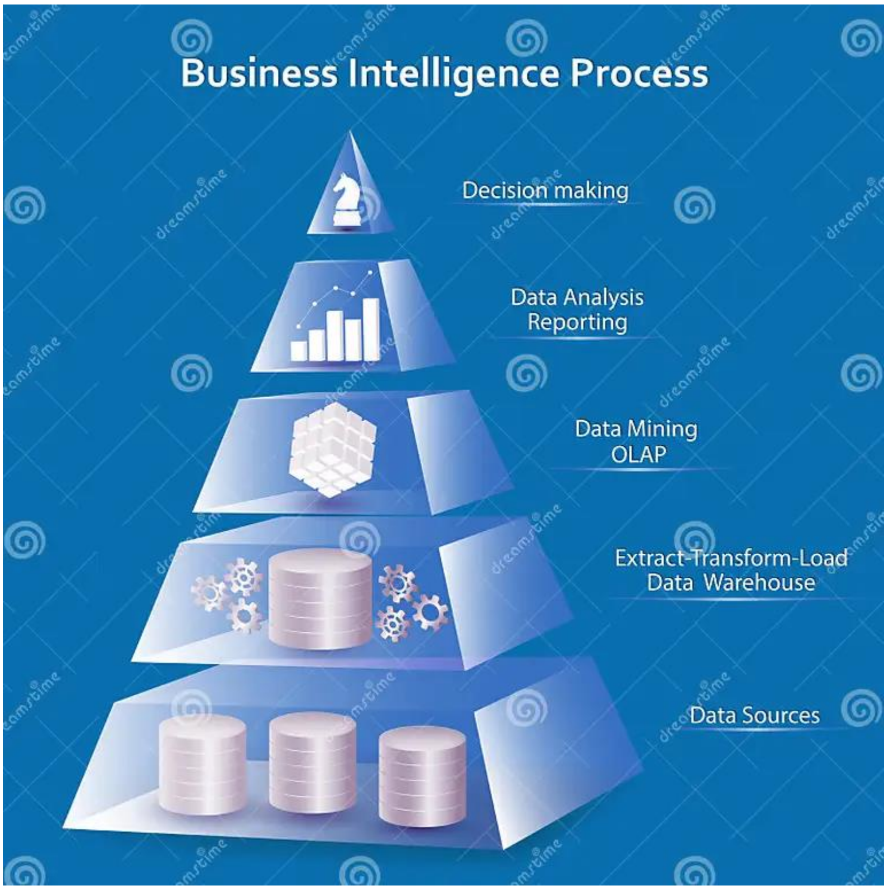


Figure 8. Business intelligence process [47].

4. Subject under study

During the investigation, 23 countries have been identified as the major holders of oil and gas resources, having the highest oil resources to invest in international companies.

Therefore, these countries are chosen as the target community to simulate these 23 countries that have the value of investing in oil resources.

The names and relative geographical locations of each of these countries are shown in **Figure 9** and are listed as:

Iran, Russia, Arabia, Iraq, Venezuela, Kuwait, UAE, US, Algeria, Canada, Nigeria, Libya, Indonesia, Australia, India, Colombia, China, Mexico, Amman, Norway, England, Qatar, Egypt, Brazil [48,49].

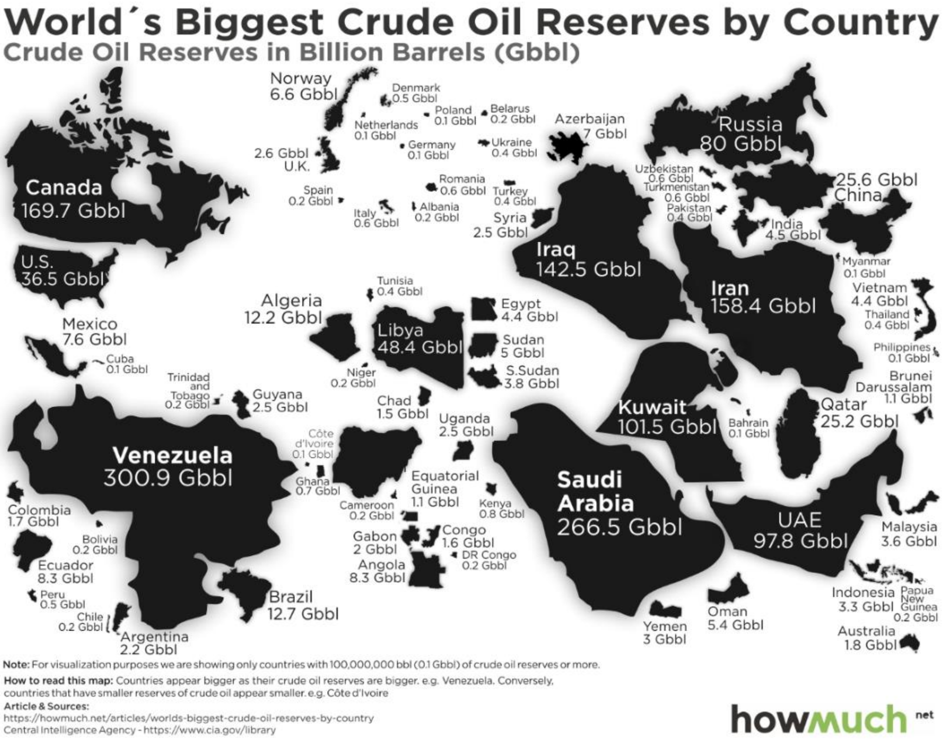


Figure 9. The subject under study [49].

4.1. Simulation

To validate the proposed method a Nano-satellite constellation covering the countries under study is designed. The STK simulation software is used for this purpose. Our goal is to provide continuous, uninterrupted coverage of oil-rich countries of the world to implement the proposed solution at the lowest cost and best quality.

4.2. Simulation steps

By repeating the simulations to achieve the desired result point, we came up with an optimal and an ideal point. At the optimum point, highest coverage time with the minimum number of Nano-satellites is achieved. At the ideal point, uninterrupted coverage using minimum number of Nano-satellites is achieved.

Assume that each transmit antenna is allowed to work on either the active radio (AR) mode or the passive radio (PR) mode, which are respectively powered by the battery as in traditional communication and the external power source as in the backscatter communication (BackCom) [50].

In the simulation of the optimal phase, we divided the Earth into 5 orbital planets and placed 7 Nano-satellites per each plane and in the simulation of the ideal stage, we divided the Earth into 6 orbital planets and placed 11 Nano-satellites on each plane.

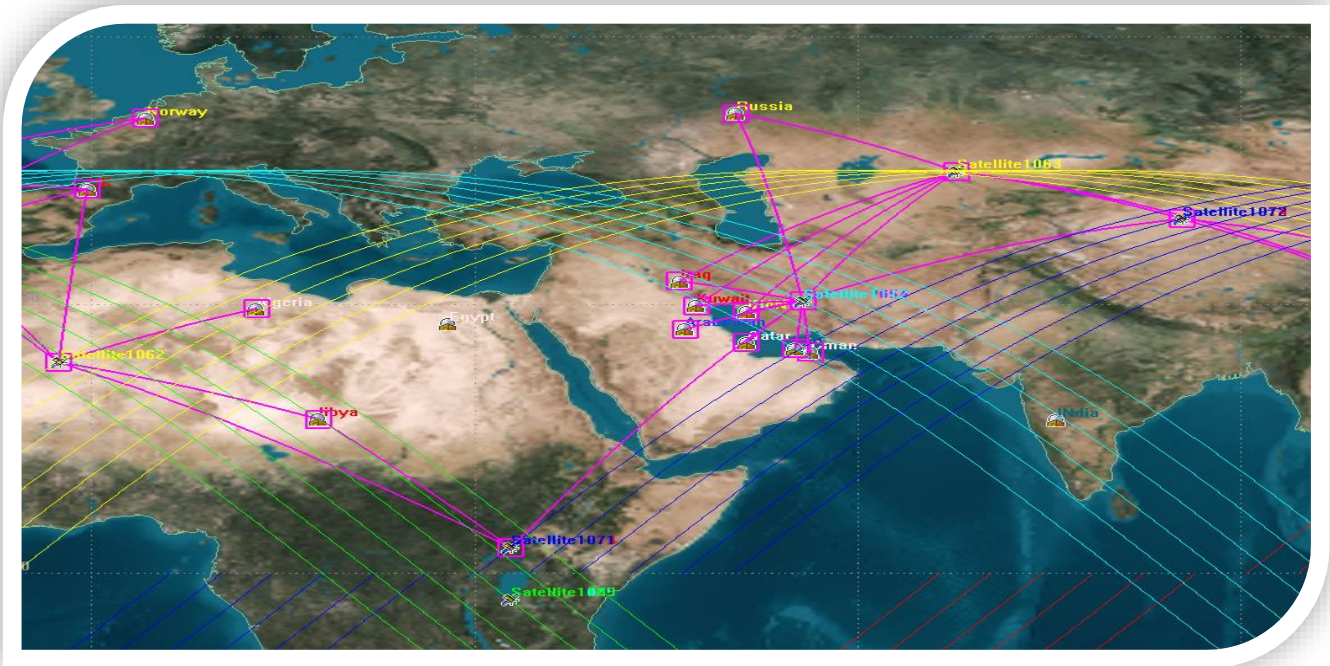
Table 1 presents basic information on the optimal and ideal simulation steps, Information such as, number of satellites per page, orbital height, inclination, type of antenna used, frequency bands, data transmission rate, simulation time.

Table 1. Simulation information table.

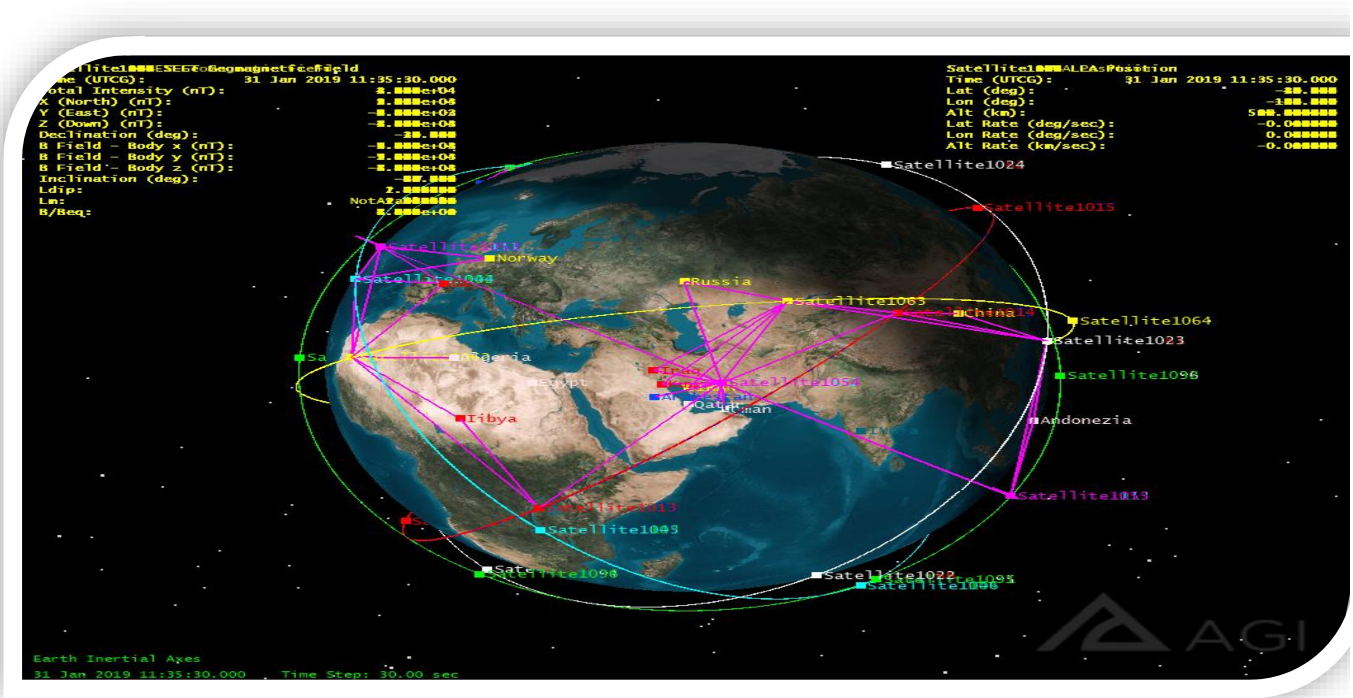
Groups	Optimal simulation	Ideal simulation
Number of ground stations	23	23
The number of orbital plates intended for Earth	5	6
The number of Nano-satellites per orbital plane	7	11
Altitude	500 KM	500 KM
Inclination	45	45
Antenna type	Elliptical antenna	Elliptical antenna
Modulation	QPSK	QPSK
ISL Band	UHF	UHF
ISL Frequency	300–3000 MHz	300–3000 MHz
GSL Band	KU	KU
GSL Frequency	16 GHz	16 GHz
Data transmission rates	16Mbps	16Mbps
Simulation time	3 Month	3 Month

As shown in the table above, we used the the frequency of f =16 GHz, 16 Mbps data rate and QPSK modulation at all stages. we also used elliptical antennas that can transmit in both vertical and horizontal polarizations. Our simulation period is 3 months

Figure 10 shows a 2D view of the simulation of the ideal stage (**Figure 10a**) and also a 3D view of the simulation for the ideal stage (**Figure 10b**).



(a)



(b)

Figure 10. simulation of the ideal stage: **(a)** 2D view; **(b)** 3D view.

4.3. Simulation results

More than 1 and 8 billion records for temporal information of the interconnection of Nano-satellites with ground stations have been reported in the ideal and optimal simulations, respectively.

Table 2 shows an example of a satellite connection time to a ground station.

Table 2. Part of simulation results from STK software.

Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
00:00.0	03:30.8	210.807
31:10.6	43:19.5	728.895
11:37.6	22:08.4	630.813
52:56.5	01:43.7	527.2
32:46.8	42:56.3	609.568
11:36.1	23:39.6	723.498
51:06.8	01:53.6	646.78
30:45.7	40:57.0	611.304
08:34.0	20:42.3	728.284
49:03.9	59:31.1	627.16

We have obtained the following results by analysing a sample of this information:

During the investigation, the disconnected time during the day to cover all the points in the system is less than 30 s on average, taking into account communications between satellites and ground stations, and less than 15 min disconnected of average time per month during the month. Which is very desirable. But for the purpose of this article, real-time communication, by increasing the number of orbits plane to 6 and considering 11 Nano-satellites in total, 66 Nano-Satellites in the system, and considering redundancy ideally, fully cover all uninterrupted locations we found.

5. Methology implementation

The cost of designing, manufacturing, and launching each nanosatellite is approximately $575,000. Considering additional launch expenses, the final cost of $1 million per nanosatellite is estimated. Consequently, the total cost of the satellite constellation, comprising 66 nanosatellites, is approximately $66 million. The constellation's minimum operational lifespan is projected to exceed two years. Therefore, given the costs associated with establishing refineries (as discussed in Section 5 and **Table 3**), this approach proves to be cost-effective.

Table 3. The impact of the proposed solution on the project implementation.

Groups	First Mega Project	Second Mega Project	Third Mega Project	Fourth Mega Project
Percentage of implementation of the solution in the project	0	10%	30%	40%
Surplus costs	60 Million Euro	40 Million Euro	25 Million Euro	12 Million Euro
Lost time	80 Month	64 Month	50 Month	36 Month
Percentage of product quality improvement	0%	0.5%	3%	4%
Percentage reduction in human resources	0%	13%	20%	27%

In terms of availability in satellite communications, the trade-off between the number of satellites and accessibility time is highly significant from a cost perspective. For instance, reducing the average 15-second daily outage to zero would necessitate doubling the number of satellites, which would result in a substantial cost increase. This trade-off highlights the economic rationale behind accepting minimal outage times in satellite operations.

The following results as shown in **Table 3**, were achieved by implementing part of the proposed project on the ongoing projects.

We have achieved the following results by implementing parts of the proposed solution on the 4 refinery and petrochemical mega project in the Middle East as the world's highest oil and gas reserves.

1) The First project, without using the proposed solution, has a € 60 million surplus cost and an 80-month increase in project time
2) The second project, with a 10% implementation of the proposed solution, has a € 40 million surplus cost and a 64-month increase in project time.
3) The third project, with a 30% implementation of the proposed solution, has a € 25 million surplus cost and a 25-month increase in project time.
4) The fourth project, with a 40% implementation of the proposed solution, has a € 12 million surplus cost and a 36-month increase in project time.
5) The key metrics for evaluating refinery quality improvements include Time-to-Repair (TTR) and Time-Between-Failures (TBF). By utilizing the proposed approach, it is possible to achieve an approximate 4% improvement in product

quality. This improvement is directly reflected in enhanced TTR and TBF performance metrics for refinery operations.

6. Conclusion

In this paper, the application of Nano-Satellites constellation in the refinery mega projects implementation has been presented. This methodology has some advantages as follows:

(1) Reduce the high cost of project implementation

(2) Reengineering organizational processes and reducing project execution time

(3) Creating organizational integration from the information point of view and enhancing information consistency in the organization

(4) Possibility to use the best standard practices in the world (Best Practices)

(5) Converting organizational processes from implicit to explicit and dramatically reducing runtime

(6) Improving the quality of the decision-making process by providing the information needed to manage the time, quality and cost.

(7) Prevent issuance of amendments to the plan, out of the ordinary

(8) Linking the work cycle of the Client, Designer and Contractor

(9) Ability to install, deploy faster systems and modules and related software in the organization

(10) Real-time processing of information and prompt delivery of reports needed for operation or consulting

(11) Choose the best vendor, the highest quality parts and the lowest quality equipment

(12) Availability of project information at any time and place

(13) Avoid excess costs due to the existing database and the identity of each part of the project

(14) Reduce project risk and risks due to full implementation of predetermined processes from beginning to end

(15) Extensibility of the organization and its infrastructure on a very large scale in order to enter into the E-Business debate

(16) Improving the quality of the decision-making process by providing the information needed to manage the time, quality and cost.

(17)Avoid excess costs due to the existing database and the identity of each part of the project

(18) Possibility or facilitation of development of new systems and technologies and system connectivity

(19) Providing the necessary infrastructure to address SCM and CRM

(20) Possibility of establishing business partnerships, joint ventures, mergers, etc. for organizations with lower costs and higher returns and better results.

Author contributions: Conceptualization, RK, HN and AM; methodology, RK, HN and AM; software, RK; formal analysis, RK, HN and AM; investigation, RK, HN and AM; resources, RK; data curation, RK; writing—original draft preparation, RK, HN and AKH; writing—review and editing, HN and AKH; visualization, RK and HN;

supervision, HN, AM and AKH; project administration, HN. All authors have read and agreed to the published version of the manuscript.

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