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Geographic Information and Cyber-Physical Systems in Oil and Gas Industry: Benefits, Problems and Integration Prospects

O. Rogach, ***O. Pidchosa**, **P. Dziuba** *(Institute of International Relations, Taras Shevchenko National University of Kyiv)*

SUMMARY

Nowadays geographic information and cyber-physical systems form the base for the new industrial revolution. In the nearest future their integration will significantly increase effectiveness of global economy and its sectors functioning, particularly, global oil and gas industry. The paper investigates the benefits and problems associated with development of geographic information and cyber-physical systems in oil and gas industry and considers a principal framework model for their integration.

Introduction. Currently geographic information systems (GIS) are developing alongside with cyber-physical (CPS) ones configuring the base for the new industrial revolution – Industry 4.0. The put forward hypothesis suggests that integrating geo-information and cyber-physical systems will substantially and positively affect he performance of the global economy as a whole and the global oil and gas (O&G) sector particularly, that is among the leaders in technological innovations. In these terms, the main goal of the present study is to analyze the benefits and problems of the development of geo-information and cyber-physical systems in O&G industry and to develop a frameworks model for their integration.

Research methods. The research has used the following methods: analysis, synthesis, induction, deduction, abstraction, system analysis, comparison, factor analysis for research of benefits and problems associated with development of GIS and CPS in oil and gas industry and their integration. We also used abstract modelling for building a complex interaction model of geo-information and cyber-physical systems in an industry; and interdisciplinary approach for estimating technological, economic, social, and environmental effects of the mentioned systems integration.

Results. Currently, the O&G companies are facing the challenges of keeping their competitiveness, optimizing production systems, increasing manufacturing efficiency, and following environmental standards. Application of artificial intelligence and digital technologies creates opportunities for increasing automatic optimized environmentally friendly production processes; allows decreasing risks and costs; more rational development of new O&G deposits; and increases safety and production levels. Therewith, a number of barriers, such as budget restrictions, organizational issues and cybersecurity, can hinder application of new technologies in oil and gas industry (Pidchosa et al., 2019). Furthermore, there are specific barriers in different markets and market groups, particularly in less developed markets where oil and gas enterprises face additional risks such as exchange rate risks, political risks etc. (Rogach & Dziuba, 2017).

In our opinion, GIS and CPS integration can help to meet these challenges, maximize positive and minimize negative effects of introducing modern technologies.

Geographic Information System is a computer-based system that allows accumulating, updating, exchanging, presenting, storing and combining spatial and non-spatial data from a variety of sources. GIS consists of hardware, software, data itself, networks and models of data analysis and provides an ability to conduct analytics necessary for further exploration (Clarke, 1986).

Cyber-physical Systems are defined as the systems that offer integration of computation, networking, and physical processes and systems where physical and software components are deeply interrelated, each operation of different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a host of factors that change with the context (Khaitan and McCalley, 2014).

Integration of GIS and CPS creates a system of computing, network and physical processes where each operation has different spatial and temporal scales, and also implies flexible models of interaction between system elements in the physical and virtual dimension depending on the context whose analysis is based on processed spatial and non-spatial data from various sources. Furthermore, we consider it necessary to study the prospects for implementation, effects and problems associated with development of GIS and CPS in oil and gas industry.

Thus, the data processed by GIS is the basic data for further use within the framework of CPS. For example, petroleum geology heavily relies on geo-information systems as the main players strive to increase efficiency, avoid environmental hazards, reduce costs and mitigate risk. Uniformed database of logging and drilling data can be formed using GIS for oil and gas exploration, as well as data on experimental analysis. Spatial data is employed basically at every stage of the life-cycle in extractive industries from exploration and extraction to abandonment of the site. For instance, an oil-field cycle can be divided into the following stages: well planning and acquisition, risk analysis, acreage analysis, prospect analysis, seismic planning, exploration, field operation, facility management, distribution and pipeline management, pipeline routing and vehicle tracking, decommissioning. At each of these, GIS can be employed to support ongoing activities and to ensure higher levels of safety and proficiency.

Exploration of new sites and promising locations is a costly process that can provide a company with a competitive advantage if completed ahead of the rivals. This process in terms of GIS functioning includes analysis of satellite imagery, digital aerial photomosaic, seismic reports, and geology studies. GIS also allows including facilities and important objects in the overlaid maps (Abdalla, 2018). Oil & gas production site planning is also performed with GIS as it is used to calculate the impact of mining on neighboring communities. Such analysis involves combining spatial data with available socioeconomic distribution, population density, labor resources, housing, and recreational infrastructure (ESRI, 2007).

Benefits of using GIS in oil and gas industry include increased efficiencies, optimized schedules and decision-making cycles, standardization, operational cost reduction, management of accidental costs, real-time digital mapping easy to use, visualization, improved communication, record keeping, new ways of responding to emergencies, optimized pipeline monitoring, use of quantitate analysis to evaluate efficiency at every stage. GIS technology is used to track geographic variables in real-time and to use interdisciplinary knowledge. It helps to eliminate duplicate data collection. All in all GIS is a centralized data sharing platform (Abdalla, 2018; Lo, 2014). Employing GIS, it is possible to identify leads, opportunities, and new prospects that allow to weigh and analyze information at hand and develop improved investment scenarios. Nowadays, GIS can be deployed not only on computers but also on mobile devices, making them available at sites ensuring situational awareness. The data are mostly automatically updated and can be sent in an aggregated form to any management levels for decision making. Working groups can collaborate and communicate via the platform and use web-based applications that help them function more efficiently. GIS nowadays offer more tools and 3D visualization. Moreover, there are GIS with new software architecture (ESRI, 2007). Thus, a classic GIS in oil and gas sector operates mostly as an integrated support system for decision making connected to: exploration, evaluation of mining conditions, modelling, displaying data, analyzing environmental impact, managing land titles, planning further activities, incorporating financial information with the aforementioned activities. Practice of using GIS points to the fact that very often the results of the spatial analysis are presented in a form of maps with spatial information on the density of production, graphic data on the dynamics of the production activities (Blachowski, 2015). GIS can be implemented for environmental risk assessment and management to evaluate the impact of potentiality hazardous substances. Risk management serves to define risks to which a system is exposed, so that policies and practices can be put in place, monitored, and reduced to acceptable levels. It considers reactive and preventive measures adopted to control and reduce the risk. For example, well field protection usually takes into account field flooding risks, septic tanks, storage tanks and industrial areas. GIS can be used for delineating buffer zones to protect well fields from such hazards (Abdalla, Wadidi, 2007). Enterprises operational and financial results in many subsectors of the O&G industry depend on the performance of complex, capital-intensive process facilities. So far, the possibilities of a company's most effective usage of its assets were limited by a number of problems. They included lack of geographical and physical proximity (e.g. deep-water) between mining and decision-making sites; large distances of land and underwater pipelines; delays between purchase and delivery of equipment and maintenance parts to the sites of exploration and hydrocarbon field management; operational changes in financial plans; ability to respond to market conditions, etc. It is CPS that can solve these problems. Any of the abovementioned positions can be considered as advanced analytical tools and techniques (even without application of artificial intelligence algorithms) to the point where they can unlock the production potential of complex process facilities and enhance asset investment returns in O&G. Moreover, they can positively transform the organizations and fundamental operating models of O&G production systems. Advanced analytics can improve subsurface activities like well placement, well design, and full-field development planning. In many ways, this approach lays the foundation for significantly lower costs and better well productivity (Dhingra et al., 2019). Also, the following basic technologies will upgrade CPS in oil and gas industry: accelerate the oilfield transactions, increase efficiency, and improve safety by removing people from harm's way; the Internet of Things will reduce the cost of repairs; machine learning will provide ever more optimal solutions to field challenges; robotics will upend the question of who performs the tasks, and blockchain will make contracting faster and smoother than ever before (Brinkman et al., 2016). Digital twins, real-time digital replicas of physical assets created by laser scanning of a construction site make it possible to do site inspections and track progress in real time from the office. With the use of radio-frequency identification and Bluetooth tagging, sensors, Internet of Things chips, parts can be automatically tracked from the manufacturer to the installation site, thus improving schedule predictability. The automated processes will enable just-in-time delivery of material and equipment. Product owners will deploy production controls to set daily targets for frontline crews, and have control meetings to increase production reliability. Lidars (laser scanners), used in conjunction with digital-twin technology, will provide a fact-based review of the work done on any given day. Used in conjunction with automated engineering processes, five-dimensional building-information modelling (5-D BIM) will likely eliminate the manual execution of many repetitive tasks, reduce the effort required for contract management, and make it possible to automate some quality-control functions. Automating and digitizing purchase-ordering processes and communications with suppliers can greatly reduce the amount of manual work required, accelerating the supply chain while giving it a totally new transparency level (Hamilton et al., 2019).

Shifts in managerial approaches are of great importance as well. O&G companies have consciously begun deploying agile management practices in the concept phase only recently. Agile relies on small, exceptionally well-coordinated cross-functional teams, rapid learning, fast technology-enabled decision cycles, and a common sense of purpose to get to key decision points faster than other approaches. It thereby allows a company to respond quickly to changes in the competitive environment (Hamilton et al., 2019; Handscomb et al., 2018). General assessment of benefits of GIS and CPS introduction in oil and gas industry indicates that they are first and foremost related to substantial cost reduction, higher safety, and sustained productivity improvement. As a result, O&G companies achieve improved health, safety, and environmental performance; better subsurface planning; higher offshore operational performance; faster, more efficient, and lower-cost supply; and reconsidered business models. Digitally enabled logistics planning under GPS monitoring and procurement execution can help ensure that transport vehicles show up on time and with the right equipment. Furthermore, clients are already digitally monitoring suppliers to ensure that the right materials are delivered on time and the price charged matches that in the contract documents. Frequent aspirations around a digitally enabled workforce is its ability to support more cross-functional teams, break up silos, and harness more institutional knowledge. More connected cross-functional teams can ensure that engineering covers appropriate risk scenarios and that contingency plans are logical and constructed to avoid decision paralysis, and better deployment of cross functional teams that operate with agile methods. Benefits such as reduced head count, higher barrel throughput, and improved safety outcomes can best be delivered by cross-functional teams (Dhingra et al., 2019). It is worth mentioning that GIS and CPS introduction in O&G industry is fraught with a number of problems. Many platform-building programs share a common problem: value capture begins only at the end, after all the pieces are in place. Multibillion investments in big data infrastructure, spanning servers, storage, networking, and software will start to pay off for at least three years, that can jeopardize the investment project, especially in conditions of fluctuating hydrocarbon prices. Furthermore, any successful technology transformation depends on having the right organizational elements in place. No matter how advanced the tool is, it will be worthless without the talent and structures for managing and using it. Many companies underestimate their opportunities for GIS and CPS introduction considering it a long, complicated and costly process (Booth et al., 2018), which is a hindering mental block for any innovation. The main culprit for a bungled automation transformation is a failure to scale. Companies often find themselves stuck in pilot mode, testing a smattering of technologies such as robotic process automation or business-process management tools to address isolated obstacles without improving end-to-end processes. Such efforts are typically not anchored in robust, comprehensive business cases that focus on transforming core processes with change management and workforce reskilling (De Jong, et al., 2019).

Conclusions. Having analyzed the benefits and problems associated with development of geo-information and cyber-physical systems in oil and gas industry we have concluded that creating and applying integrated GIS and CPS (Figure 1) results in a complex positive synergetic effect of their joint employment in production, financial, environmental, managerial and social fields. The problems associated with O&G companies functioning and connected with introduction and further maintenance of these systems are also minimized. GIS and CPS complement each other: GIS are oriented on analytical functions and decision-making support, while CPS provide for their implementation with maximum positive outcome.

Investing in integrated GIS-CPS system refers to capital expenditures and the return on such investment (depending on many factors) is expected after three to five years. It is recommended to introduce the systems according to modular principle, i.e. an O&G company chooses the modules based on its size and segment of operation, geographical scattering, total or partial value chain control or its investment priorities. Modules that provide the highest production level and profit should be considered the best. At the next stage the company should introduce additional modules, such as launching an integrated GIS-CPS model, that can become a technologically complex and costly task, being even more complicated considering the need in recruiting the properly qualified staff. The keystone of the integrated GIS-CPS system is a data processing center, operational monitoring and data collecting GIS, e-procurement system, remote production control system. It is especially urgent that the system is cyber secured providing both physical and economic security of the O&G company, its employees, local communities, environment and connected infrastructure.

The data generated by this system functioning can make the company operating more transparent for shareholders and will have a positive effect on its capitalization and investment attractiveness. Provision access to integrated GIS-CPS system data, which are not a trade secret, to local communities could become a further step in corporate social responsibility strategy.

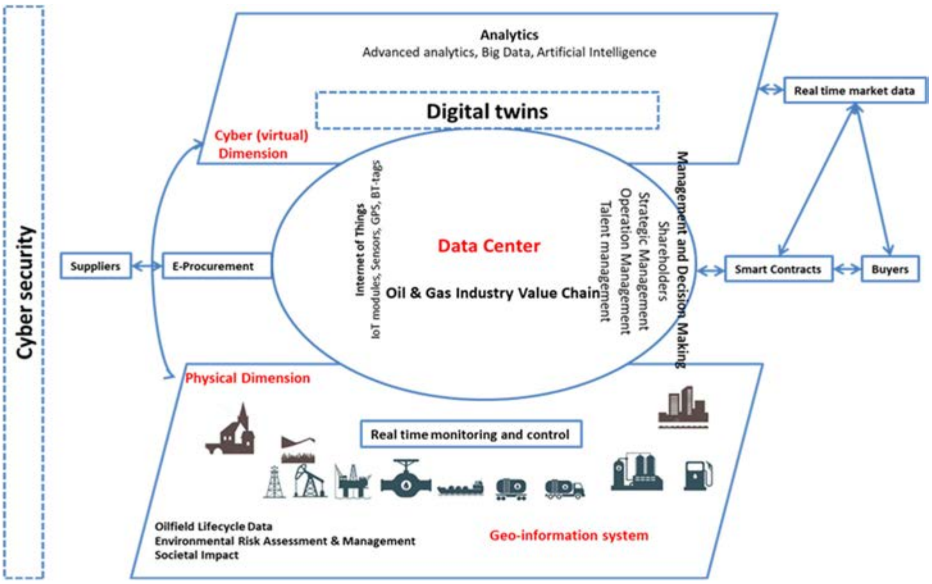

Figure 1 *Principal framework model of Integrated GIS-CPS system*

Source: developed by the authors.

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