MULTI-CRITERIA RISK-ORIENTED SELECTION OF A SITE AND TECHNOLOGY FOR BUILDING A DATA CENTER IN ENERGY-LIMITED REGIONS

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Abstract

The article presents a multi-criteria risk-oriented approach to selecting a site and technology for building data centers (DCs) in energy-constrained regions. The methodology takes into account construction technology, logistical accessibility, climatic and geotechnical risks, readiness for power supply and connectivity of utility systems. Particular attention is paid to the integration of digital tools (GIS–BIM, MCDM) and risk analysis related to power supply, logistics and water supply. Examples of comparative analysis of traditional and modular construction are given, and the advantages of industrialized solutions for accelerating deadlines and reducing risks are shown. The proposed approach allows for the formation of a formalized risk profile and making informed decisions taking into account the specifics of the region.

Keywords: risk-based approach, multi-criteria choice, energy-constrained regions, construction of data processing centers

I. Introduction

The development of the digital economy and the exponential growth of data volumes lead to increased demand for data processing centers (DPCs) even outside the capital regions [1]. However, in remote and energy-limited regions, the construction of data centers is associated with particular difficulties. Southern regions, for example, experience a shortage of available energy capacity due to climatic conditions, although the business need for local data centers for storing and processing data is high. [2]. The correct choice of site for the data center in such conditions is critically important: a good location lays the foundation for reliable operation, while the wrong choice leads to constant problems and financial losses. [3][4]. Moreover, problems caused by incorrect site selection usually only become apparent at the final stages of construction and commissioning of the facility, when it is already too late or extremely expensive to correct anything.

Research related to the subject of this work is gradually shifting the focus from "pure" energy efficiency to the risks of construction feasibility and availability of energy resources. At the level of pre-project preparation, it is indicative to use multi-factor models of geographic information systems (GIS models) for preliminary ranking of sites taking into account geotechnical factors, hydrological hazards, and transport restrictions. Work on integrating geotechnical, environmental, geophysical, and transport factors into site selection demonstrates a measurable effect on reducing construction risks [5]. A similar approach is the integration geographic information systems with an object-oriented model of a construction site or complex of construction sites (GIS–BIM) for constructing geotechnical models and “safe construction zones”, which allows for the early identification of areas with unfavorable soils, risks of flooding/landslides and the adjustment of the layout of engineering infrastructure facilities of the data center [6].

Construction deadlines and logistics are a separate block. Comparisons of “classical” and automated planning show that 4D-BIM increases the predictability of deadlines due to the link between the calendar, model and real availability of resources, which is especially critical for remote sites and cramped construction zones [7].

II. Risk analysis of data center project

A separate area is risks, as a determining critical path of a data center project. Empirical reviews of intersystem queues for connection to networks record median expectations from ~ 4 to 5 years from application to commissioning for projects in recent years. Power supply and network reinforcements often take longer than the actual construction cycle [8]. Industry analysts supplement this with practical assessments: long lead times for transformers/busbars and complete switchgear (CSG) (up to several years), as well as protracted technical connection procedures, increase the uncertainty of the schedule and financial risks associated with capital expenditures (CAPEX risks) [9]. For energy-deficient regions, this means the need to include network risks in multi-criteria construction decisions, for example, consider phased capacity expansion and modular substations.

A related class of risks is disruption of construction supply chains. Surveys of risk management in construction supply chains highlight the growing vulnerabilities at the intersection of procurement, heavy-duty logistics, special equipment and personnel. Formed recommendations in the form of risk matrices for process management [10].

Industrialized construction is considered as a means of reducing calendar and logistical risks: prefabrication of modules, engineering solutions, power units and modular machine rooms. Reviews of modular construction show that optimization of production and installation schedules provides benefits in terms of duration and variability of deadlines [11], and studies of prefabricated objects record the influence of the selected technology and delivery system on the actual duration of work [12]. In the context of data centers, this directly translates into a reduction in work in unfavorable climates and on narrow sites, as well as the ability to accelerate the introduction of queues with restrictions on network connections [9, 11 - 12].

Construction solutions for heat removal also have a risk dimension: ensuring water supply and drainage, placing cooling towers and dry coolers, and complying with noise standards. Studies on data center water consumption demonstrate significant data uncertainty and a high share of potable water in a number of scenarios - this increases permitting and infrastructure risks in water-deficient basins [13]. On the technology side, a number of recent studies and tests record a shift towards liquid cooling, which structurally reduces dependence on water, simplifies placement in cramped areas, increases the temperature of the coolant and opens the way to heat recovery [14 – 17]. For builders, this means a shift in the layout of engineering systems (collectors, heat exchangers and pumps) and in the requirements for installation and commissioning, as well as new supply risks [18].

For cold regions, research focuses on geocryological risks: frost heave, thawing, subsidence, impact on foundations and linear networks. Research [19] summarizes risk assessment methods and emphasizes the need to adapt foundation and drainage designs to changing permafrost. Current guidelines for Arctic construction systematize design solutions and construction practices - seasonality, winter downtime, roads, insulation and thermal stabilization of soils [20]. Russian research assesses the socio-economic consequences of permafrost degradation and brings legal and organizational aspects to the management of construction risks in the North [20, 22]. For data centers, this translates into requirements for the choice of foundation type (pile systems, grillages with thermal stabilization), site drainage, winter concreting technologies and logistics of heavy modules.

Finally, in terms of risk-oriented multi-criteria choice methods in construction, hybrid multi-criteria decision-making methods are used to rank risks, select technologies, and structure alternatives under high uncertainty [10 – 12, 21]. These tools combine well with GIS–BIM [5 – 8] and allow for the integration of construction and technological risks (geotechnics, seasonality, logistics, supplies, water infrastructure) into a single model, along with cost, timing, and sustainability criteria.

The task of choosing the optimal site for a data center generally requires taking into account a wide range of criteria, since there are no standardized methods for all cases. In the practice of data center construction, each new project is forced to form its own list of requirements and criteria, based on open sources, expert advice and previous experience.

Within the framework of the risk-oriented approach, the following procedure is proposed:

1. Identify all key factors that influence the success of the project;
2. For each factor, assess the risks associated with it (probability and potential damage);
3. Assign a “weight” or priority to criteria based on the significance of the risks involved;
4. Conduct a comparative assessment of alternative sites and construction technologies based on a set of criteria.

III. Criteria for assessing the risks of a data center project

A weighted assessment can be used to quantitatively integrate different factors. Based on the algorithm described above, as well as an analysis of studies on the topic, the following criteria were formulated:

1) Erection technology (industrialization). Research on modular and industrialized construction shows that increased factory readiness, standardization of units, and parallelization of work reduce the duration and variability of deadlines. A systematic review of production planning in modular construction confirms these advantages and the maturity of optimization methods.

2) Construction and logistics accessibility of the site. Large-scale equipment logistics, access road restrictions, crane zones and construction site layout are drivers of delays and cost overruns; reviews show a direct link between the quality of the logistics organization and productivity and safety.

3) Climatic and geotechnical exposure of construction processes. In cold and difficult natural conditions (permafrost, floods, seismicity) the risk of special events and "weather windows" increases, which affects the timing and cost of work; these effects are confirmed by review studies.

4) Readiness of power connection (time - to - power). For energy-deficient regions, the timing and reliability of technological connection are a critical path of the project; reports and roadmaps record long queues and delays.

5) Connectivity of utility systems (water, sewerage, heat, communications). Water capacity and water use limits limit the choice of cooling technologies, waste heat utilization and the presence of heating networks can reduce the overall risk and improve the project economy,

telecom infrastructure factors are also important.

IV. Multi-criteria risk-oriented principle

Based on these criteria, the proposed multi-criteria risk-oriented principle was formed. The alternative is considered as a combination of the site S and the technological solution for construction, cooling τ: a=(s,τ). The integrated assessment is based on five criteria reflecting the contribution of the construction industry to the feasibility of the project:

U_1 — construction manufacturability;

U_2 — construction and logistics accessibility;

U_3 — climatic and geotechnical exposure;

U_4 — readiness of power connection;

U_5 — connectivity of engineering systems.

Standardization of indicators: let Cjk(a) — the measured indicator k within the criterion j. Min – max -norming is applied:

"More is better":

$$c_{jk}(a) = \frac{x_{jk}(a) - \min x_{jk}}{\max x_{jk} - \min x_{jk}}$$

"Less is more":

$$c_{jk}(a) = \frac{\max x_{jk} - x_{jk}(a)}{\max x_{jk} - \min x_{jk}}$$

Aggregation indicators in the criterion:

$$U_j(a) = \sum_k v_{jk} c_{jk}(a), \;\; v_{jk} \geq 0, \;\; \sum_k v_{jk} = 1$$

Risk assessment according to criteria:

- An expert-analytical approach (FMEA):

$$R_j(a) = \frac{1}{125 N_j} \sum_{r=1}^{N_j} P_{jr} I_{jr} D_{jr}$$

- Scenario approach (if statistics are available):

$$R_j(a) = \frac{\mathrm{CVaR}_\alpha [L_j(a, \omega)]}{\max_a \mathrm{CVaR}_\alpha [L_j(a, \omega)]}$$

Final integrated assessment of the alternative:

$$S(a) = \sum_{j=1}^{5} w_j (U_j(a) - \gamma_j R_j(a))$$

where Uj are the normalized indicators according to the criteria, Rj are their risk indices, wj are the importance weights, γj are the risk aversion coefficients

The higher the S(a), the more preferable the project. Before ranking, strict cutoffs are applied according to regulatory and resource restrictions (zoning, sanitary requirements, water limits, deadlines for technological connection).

V. Results and discussion

The application of the described approach in real projects allows to significantly improve the validity of decisions on the localization of the data center and the choice of technology for its implementation. Each potential site option is assessed comprehensively: not only by capital costs or proximity to customers, but also by the total risk of failures and losses over the operational horizon. Risk-oriented choice means that preference is given to the option that minimizes the likelihood of major negative events (accidents, interruptions, business downtime) with acceptable costs for preventive measures.

Let's consider a hypothetical scenario: a commercial data center is planned to be built in the south of Russia, where demand for services is high, but the region is characterized by a hot climate and a shortage of available electric power capacity. Using a multi-criteria approach, several alternative regions or specific sites can be compared. For example, Option A is a site in the most energy-deficient southern region, and Option B is a site in a more northern region with better power supply. Option A may have the advantage of being closer to the customer base (less latency and higher commercial potential), but is accompanied by high risks: the need for an expensive cooling system with cooling towers due to the hot climate, investments in new energy infrastructure (lines from a remote substation), possible power outages during peak summer months. Option B, on the contrary, can offer stable power supply from hydropower and natural cooling for most of the year (low energy efficiency rating), but is located further from consumers, and the infrastructure (roads, communications) is weaker. The decision in this case is made based on the total risk scores: if the risk of failure and the cost of insuring it (redundancy, diesel generators, excess cooling capacity) outweigh the benefits of the location, then Option A is considered inappropriate. Thus, the multi-criteria approach allows for a transparent justification of the choice: either to build a data center where reliability is higher, or to take clearly planned measures to neutralize the risks of an unfavorable location.

As for the construction technology, the approach is similar - alternatives are assessed (for example, traditional capital construction versus a modular data center from factory-made products) in terms of their impact on project risks. Experience in data center construction in regional conditions shows a significant difference between these approaches. For example, the Key Point Group of Companies tested both options when implementing projects in Vladivostok and Novosibirsk. In Vladivostok, the classic approach was used: all work was performed on site, a capital building for the data center was erected from scratch. In Novosibirsk, on the contrary, they decided to speed up construction and improve the quality of the facility due to modular technology using ready-made factory units. Already assembled modules were delivered to the site, quickly installed and connected to the system. The results were impressive: the Novosibirsk Tier III data center was built in a short time (the first stage of 440 racks was commissioned in 12 months, and the expansion by another 440 racks will take only ~5 months). The quality of execution has improved, and the number of human errors has decreased due to the high factory readiness of solutions. In addition, the modular data center is easier to maintain - access to systems is simplified due to the block structure, which also reduces operational risks.

The choice of modern construction technology, such as modular, can be considered as a risk management tool: reducing the risks of failure to meet deadlines, exceeding the budget and the occurrence of defects. Of course, the modular approach may require developed logistics for the delivery of large modules, but in most cases, the benefits in speed and reliability outweigh these. In general, the influence of the construction industry is clearly visible: the use of advanced engineering solutions and cooperation with experienced contractors allows us to mitigate many risks that are typical for projects in remote and infrastructure-weak regions.

By applying the proposed multifactorial approach, it is possible to form a formalized risk profile for each project option under consideration. This allows for a reasonable choice of the option with the lowest acceptable risk instead of relying only on cost and assumptions. In energy-constrained regions, this is especially important, since the environment itself increases the likelihood of adverse incidents. Risk-oriented planning allows for the adaptation of the project to these conditions: to provide for additional power sources, enhanced cooling, a remote monitoring and control system to minimize personnel visits to a remote facility. The selected site and construction technology will ensure the required level of reliability (SLA) and data security, despite external restrictions.

VI. Conclusion

Building a data center in an energy-deficient region is a complex multifaceted task, the success of which depends on the right strategic decisions at the start. The analysis showed that a comprehensive risk-oriented approach to choosing a location and technology for implementing a data center is needed. Firstly, relying only on generally accepted standards and typical practices is not enough - it is necessary to develop an individual list of criteria and requirements for the site, taking into account the specifics of the project. Secondly, even before the start of construction, it is necessary to form your own set of rules and a methodology for evaluating options, including using recommendations and "elements" from the experience of previous projects. Thirdly, it is necessary to distribute priorities between criteria in proportion to the degree of risk: factors critical to reliability should receive maximum attention. Compliance with these principles can significantly reduce the likelihood of errors in choosing a site and, as a result, avoid serious consequences during the operation of the data center. The result of applying the methodology is a reasonable choice of the optimal region, a specific site and a format for building a data center, which achieves a balance between costs and the level of risk.

CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

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