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CASE STUDY

Organizational and Technological Justification for the Use of a Mobile Dismountable Hydraulic Drilling Rig for Water Well Construction under Restricted Access Conditions

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Abstract

Drilling operations in developed residential areas are constrained by narrow access routes, fences, pavements, and landscaping elements. The aim of this study is to develop and substantiate an organizational and technological approach to the use of a mobile dismountable hydraulic drilling rig for water well construction under restricted access conditions. The study is based on a private residential site where the minimum passage width between the building and the fence was 1.1 - 1.2 m. Bringing a conventional heavy drilling unit directly to the drilling point would have required dismantling the fence and part of the landscaping followed by restoration works. The methods included engineering site inspection, dimensional analysis of equipment, decomposition of technological operations, comparison of two work organization alternatives, and normalized cost assessment. The investigated rig has a height of 2320 mm, a load-bearing structure width of 300 mm, a drilling table size of 300 × 310 mm, a disassembled set mass of approximately 250 kg, and an assembled operating mass of approximately 350 - 400 kg. A technological accessibility coefficient is proposed to relate the minimum passage width to the critical transverse dimension of a transported module. For a 630 mm module, the coefficient equals 1.75 for a 1100 mm passage and 1.90 for a 1200 mm passage, with geometric clearances of 470 and 570 mm, respectively. An organizational and technological algorithm is developed covering site inspection, route verification, module transportation, assembly, drilling, disassembly, and performance assessment. Eliminating temporary access preparation removes a group of costs estimated at 35 - 40% of the base project cost. The economic result is therefore interpreted as a consequence of the engineering and technological decision.

Keywords: drilling rig, water well, restricted access, hydraulic drive, modular design, technological accessibility, drilling operations

Introduction

When constructing a water well within an established residential area, constraints that rarely arise on an undeveloped site must be taken into account. Equipment selection is therefore influenced by the presence of buildings, fences, paved surfaces, landscaping, underground utilities, and other site elements, as well as by the actual width of the delivery route. In densely developed areas, the technical possibility of positioning a rig at the drilling point does not necessarily mean that the rig can be delivered there because of site-specific access constraints.

In particular, the location and design parameters of a water well should be based on information about hydrogeological conditions and aquifer properties. Studies of water-supply facilities indicate the need for preliminary geophysical and geological justification of the drilling point, since the characteristics of the geological section determine the prospects of water-bearing zones and the requirements for subsequent well construction [1]. In this study, this principle is adopted as an initial condition because equipment accessibility is assessed after the design drilling point has been determined and does not substitute for hydrogeological justification.

Selection of drilling equipment is generally associated with lifting capacity, power parameters, transportation, installation, and operating costs. The functional-structural approach to drilling rig selection supports considering the equipment's technical functions together with transportation, installation, and operating costs [2]. When work is performed on a developed site, delivery to the operating point becomes particularly important because access itself may limit the use of a high-capacity machine.

Russian researchers consider mobile drilling solutions a means of reducing preparatory work and improving equipment accessibility at sites with difficult placement conditions. Experience in developing mobile drilling rigs shows that reduced transport dimensions and the ability to move equipment between operating points can act as independent efficiency factors [3]. In private residential development, the spatial scale of this problem is smaller, but its engineering substance remains similar: the equipment must reach the drilling point without unacceptable interference with the existing site.

The use of hydraulic drives in drilling machines is, among other reasons, associated with the ability to regulate the force and speed parameters of actuating mechanisms. Industry literature notes the widespread use of hydraulic drives in drilling equipment when working movements must be controlled under variable loads [4]. For a mobile rig, this characteristic is important because of the limited dimensions of the working equipment and the need to provide both feed and rotation of the drilling tool.

Technical assessment of a mobile machine should take into account the parameters of working motions and the possibility of recording them. Studies of mobile drilling rigs emphasize the value of monitoring pressure, rotational speed, and other drilling-process characteristics to evaluate drive performance and the operating mode [5]. Advances in hydraulic-drive monitoring also make it possible to record kinematic, force, and energy parameters directly during operation [6]. For industrial validation of the proposed approach, such measurements provide the basis for subsequent comparison of mobile and conventional technologies.

Hydraulic-drive reliability also affects actual productivity. In particular, failures of the drive systems of mobile drilling machines cause downtime, which directly increases work duration and cost [7]. For this reason, the criterion of technological applicability should not be limited to whether the equipment can pass through a narrow section; after delivery and assembly, the rig must also retain the required operability, reliability, and maintainability.

The drilling process itself requires appropriate selection of circulation parameters and the hydraulic regime. Russian studies of hydraulic calculations in drilling emphasize the need to account for pressure losses and flow conditions of the working fluid when selecting process parameters [8]. In the present study, the accessibility calculations are treated as a preliminary criterion for admitting equipment to the next stage of engineering analysis.

The method used to move a drilling rig can affect the overall duration of well construction. Production experience with rig-moving systems shows that reducing relocations and rig-up operations yields a measurable time-related effect [9]. At private residential sites, the same principle is implemented by changing the transport configuration of the equipment: instead of moving the assembled rig, a set of modules is transported through the existing passage and connected at the operating point.

The central scientific problem addressed in this study is the absence of a quantitative criterion linking the geometric constraints of an existing site with the transport configuration of a dismountable drilling rig and the subsequent organization of work. A related issue concerns economic assessment: without such a criterion, alternatives may be compared even when one of them technically requires prior modification of the site, making it impractical or inapplicable from an engineering standpoint.

The aim of the study is to develop an organizational and technological approach to the use of a mobile dismountable hydraulic drilling rig for water well construction under restricted access conditions.

To achieve this aim, the following tasks were completed:

1. the initial site constraints were identified;
2. the dimensional and mass parameters of the rig were systematized;
3. a technological accessibility coefficient was proposed and an equipment delivery and deployment algorithm was developed;
4. the composition of operations for the heavy-rig and mobile-rig alternatives was compared;
5. a normalized assessment was performed of the cost effect resulting from elimination of dismantling and restoration works.

The scientific novelty of the study lies in formalizing the relationship between the minimum width of the delivery route, the transverse dimension of the transported module, and the organization of subsequent drilling operations. In addition, a causal model is proposed in which a change in the transport configuration of the equipment changes the composition of technological operations and consequently affects project duration, labor input, and cost.

Materials and Methods

The study is based on a practical case involving construction of a water well at an existing private residential property. The minimum passage width between the house and the fence was 1.1 - 1.2 m. Direct access of a heavy drilling machine to the drilling point was unavailable. Creating a temporary access route would have required partial dismantling of the fence, interference with existing landscaping, and subsequent restoration of the site. According to the contractor's preliminary estimate, this group of works would have increased the base project cost by approximately 35 - 40%. The customer rejected the option involving damage to paths and other site elements.

A modular mobile hydraulic rig was selected as the engineering solution; the equipment is delivered to the work site in a disassembled state. Individual components are carried by a crew of 2 - 3 people in several trips and assembled directly at the work area. The total mass of the disassembled set is approximately 250 kg. When preparing the method statement, however, the mass of each module must be considered separately and a safe handling method selected.

Selected provisions concerning mobile drilling systems, hydraulic drives, and the economics of drilling projects were used as the theoretical basis of the study. These provisions were further developed in relation to the physical accessibility of the operating point and transformed into a quantitative criterion and a sequence of engineering actions. The initial technical parameters of the mobile dismountable drilling rig are presented in Table 1:

Table 1. Initial technical parameters of the mobile dismountable drilling rig

Parameter	Value
Rig height in assembled condition	2320 mm
Width of load-bearing structure	300 mm
Drilling table dimensions	300 × 310 mm
Mass of disassembled set	approximately 250 kg
Mass of rig in assembled operating condition	approximately 350 - 400 kg
Oil tank dimensions	300 × 360 × 100 mm
Hydraulic tank dimensions of power unit	630 × 500 × 190 mm
Delivery method to restricted-access site	as individual modules
Crew size for manual transport	2 - 3 people
Final assembly location	directly at the site

Source: compiled by the author based on technical data for the rig under study.

The surface area of the drilling table is determined from its dimensions of 300 × 310 mm:

$$S_{dt} = 0.300 \cdot 0.310 = 0.093 m^2. \quad (1)$$

The resulting value characterizes the surface area of the structural element and does not correspond to the total required working area. Safe deployment requires additional space for supports, the operator, tools, hydraulic lines, and auxiliary operations.

International experience with portable fully hydraulic rigs confirms the engineering significance of dismountability, the low mass of individual components, and reduced mobilization labor [10]. At the site considered in this study, this principle is applied under more constrained residential conditions. The operating dimensions of the rig are retained after assembly, whereas the requirement for passing through a narrow route applies to the dimensions of the transported modules.

For preliminary assessment of geometric applicability, the technological accessibility coefficient is proposed:

$$K_a = \frac{B_{min}}{b_m}, \quad (2)$$

where K_a is the technological accessibility coefficient; B_{min} is the minimum passage width along the transportation route, mm; b_m is the critical transverse dimension of the transported module, taking into account its selected orientation during handling, mm.

The condition for preliminary geometric applicability is written as:

$$K_a > 1. \quad (3)$$

If $K_a \leq 1$ the module cannot be moved through the section under consideration without changing its orientation, disassembling it into smaller components, or preparing access. If $K_a > 1$ a geometric clearance is available; the final decision additionally takes into account passage height, route turns, protruding elements, elevation changes, safe gripping conditions, component mass, and surface condition.

International studies of portable drilling machines show that limited site accessibility alone can justify the use of equipment that is transported by two or more workers and allows drilling where conventional machinery is difficult to deploy [11]. Accordingly, manual transport of modules is treated as a separate stage of the technological process and should be included in time studies.

As a conservative value of the critical dimension, the largest of the specified dimensions of the individual components - 630 mm - was used. For a minimum passage width of 1100 mm $K_{a,1100} = \frac{1100}{630} = 1.75$. For a passage width of 1200 mm $K_{a,1200} = \frac{1200}{630} = 1.90$.

The geometric clearance is determined by the expression:

$$\Delta B = B_{min} - b_m. \quad (4)$$

For the two limits of the actual passage width, the resulting clearances are 470 and 570 mm, respectively (Table 2).

Table 2. Calculation of technological accessibility for the specified critical dimension

Passage width, mm	Critical module dimension, mm	K_a	Geometric clearance ΔB, mm	Preliminary conclusion
1100	630	1.75	470	geometric passage is feasible
1200	630	1.90	570	geometric passage is feasible

Source: author's calculation.

Experimental evaluation of a portable water-well drilling rig shows that equipment comparisons should record penetration rate, torque, energy consumption, and deployment time [12]. Actual values of these indicators are not available in the present study and therefore are not replaced by calculated assumptions; however, for further validation they should be included in the list of mandatory production observations.

The total duration of the work is represented as the sum of the technological stages:

$$T_\Sigma = T_{mob} + T_{assm} + T_{dr} + T_{aux} + T_{demob} + T_{rest}. \quad (5)$$

where T_{mob} is mobilization and delivery; T_{assm} is rig assembly and preparation; T_{dr} is net drilling time; T_{aux} is auxiliary operations; T_{demob} is disassembly and removal; T_{rest} is restoration of disturbed site elements.

Labor input is determined as the sum of labor expenditures by operation:

$$H_\Sigma = \sum_{i=1}^{m} n_i t_i, \quad (6)$$

where n_i is the number of workers engaged in the i -th operation; t_i is its duration, h.

With time-study data available, the mechanical penetration rate is calculated as:

$$v_m = \frac{L}{T_{dr}}, \quad (7)$$

where L is the actual drilled length, m.

Specific energy consumption or fuel consumption can be estimated as the ratio of resource consumption to drilled length:

$$q = \frac{Q}{L}. \quad (8)$$

Operation of the hydraulic drive under variable external loads requires monitoring of speed and operating stability under the selected operating mode. For example, experimental studies of hydraulic top drives demonstrate a relationship between load fluctuations and output speed and indicate the need to regulate drive parameters [13]. Therefore, subsequent validation should additionally record hydraulic-system pressure, rotational speed, and the pattern of technological stops.

Laboratory studies of drilling rigs confirm the value of systematically recording parameters under different operating modes and rock types to establish the equipment's operating limits [14]. Under the proposed methodology, the production experiment should be conducted at a series of sites with geological conditions recorded so that differences in penetration are not attributed to the rig type without considering the properties of the drilled formation.

Results and Discussion

Engineering inspection showed that transport accessibility of the operating point was the decisive constraint at the study site. The existing passage width of 1.1 - 1.2 m prevented direct entry of a conventional heavy drilling machine. The technical task was therefore to decouple the full operating dimensions of the rig from the dimensions that must pass along the delivery route.

The modular configuration addresses this task by sequentially changing the state of the equipment. During mobilization, the rig is a set of individual components. Each component is carried through the existing passage. Once delivery is complete, the rig is assembled, aligned, secured, and connected to the hydraulic system. The operating configuration is formed directly at the drilling point. As a result, the delivery route is checked against the module dimensions, whereas the work area is assessed against the assembled rig.

Calculation using Eq. (2) shows that, for the known dimension of 630 mm, even the minimum passage width of 1100 mm yields an accessibility coefficient of 1.75; the resulting 470 mm clearance is sufficient for a positive preliminary geometric check (Table 3). For a 1200 mm passage, the coefficient increases to 1.90 and the clearance to 570 mm. Nevertheless, each individual module and all turning sections of the route must still be checked on site.

Table 3. Comparison of work organization for the two technological alternatives

Criterion	Alternative A: heavy drilling rig	Alternative B: mobile dismountable rig
Equipment state during delivery	transport or self-propelled machine	individual modules
Passage along existing 1.1 - 1.2 m route	not feasible at the site under consideration	feasible after module verification
Creation of temporary access route	required	not required
Fence dismantling	required	eliminated
Impact on landscaping	substantial	localized within the work area
Assembly at drilling point	limited machine preparation	mandatory technological operation
Manual transport of components	not used	crew of 2 - 3 people
Mass distribution during mobilization	mass concentrated in the transport unit	mass distributed among modules
Main source of additional work	access provision and restoration	rig assembly and disassembly
Requirement for production assessment	account for access preparation	account for transport and assembly operations

Source: compiled by the author.

Based on the results, an organizational and technological algorithm was developed. Its core principle is that access is checked before the equipment is mobilized. First, the design drilling point and the delivery route are determined; then the critical dimensions of passages are measured, and the parameters of the rig and transported modules are established. After calculating K_a , a decision is made on whether safe delivery is possible. If the result is negative, the route, equipment configuration, or access-preparation method is changed. If it is positive, the module delivery sequence is established, the local work area is prepared, and assembly and readiness checks are performed. Drilling, disassembly, removal, and performance assessment then follow.

Including assembly in the list of technological operations is essential because, for a heavy machine, time is spent primarily on creating access, delivering the equipment, and subsequently restoring the site. With modular equipment, part of these operations is replaced by carrying individual components and assembling the rig. Comparing only net drilling time is therefore inappropriate because such an assessment excludes stages required to actually start and complete the work at a particular site.

Table 4. Indicators for production validation

Group	Indicator	Unit	Acquisition method
Delivery	module delivery duration	min	time study
Assembly	assembly and alignment time	min	time study
Labor	total labor input	person-h	calculation by operation
Drilling	net drilling time	h	work log
Drilling	mechanical penetration rate	m/h	calculated by Eq. (7)
Drive	hydraulic-system pressure	MPa	measurement
Drive	rotational speed	rpm	measurement
Energy	fuel or electricity consumption	L; kWh	resource accounting
Energy	specific consumption	L/m; kWh/m	calculated by Eq. (8)
Downtime	duration of technological stops	min	time study
Completion	disassembly and removal time	min	time study
Site	restoration work time	min	time study

Source: developed by the author.

The normalized cost model is based on the base project cost C_0 , which excludes dismantling and restoration of access-related elements. For the heavy-equipment alternative, the preliminary estimate of additional work is 35 - 40% of C_0 . Then:

$$C_A = 1.35C_0 \ldots 1.40C_0 \quad (9)$$

The mobile alternative eliminates this particular group of works. With the other cost components assumed unchanged, the normalized cost of the part under consideration for Alternative B is taken as C_0 . This assumption is used only to isolate the access-related effect and does not represent a calculation of the total drilling cost.

The share of the eliminated access-preparation and restoration costs in the total cost of the heavy-rig alternative is determined as:

$$E_{35} = \frac{0.35}{1.35} \cdot 100\% = 25.9\%, \quad (10)$$

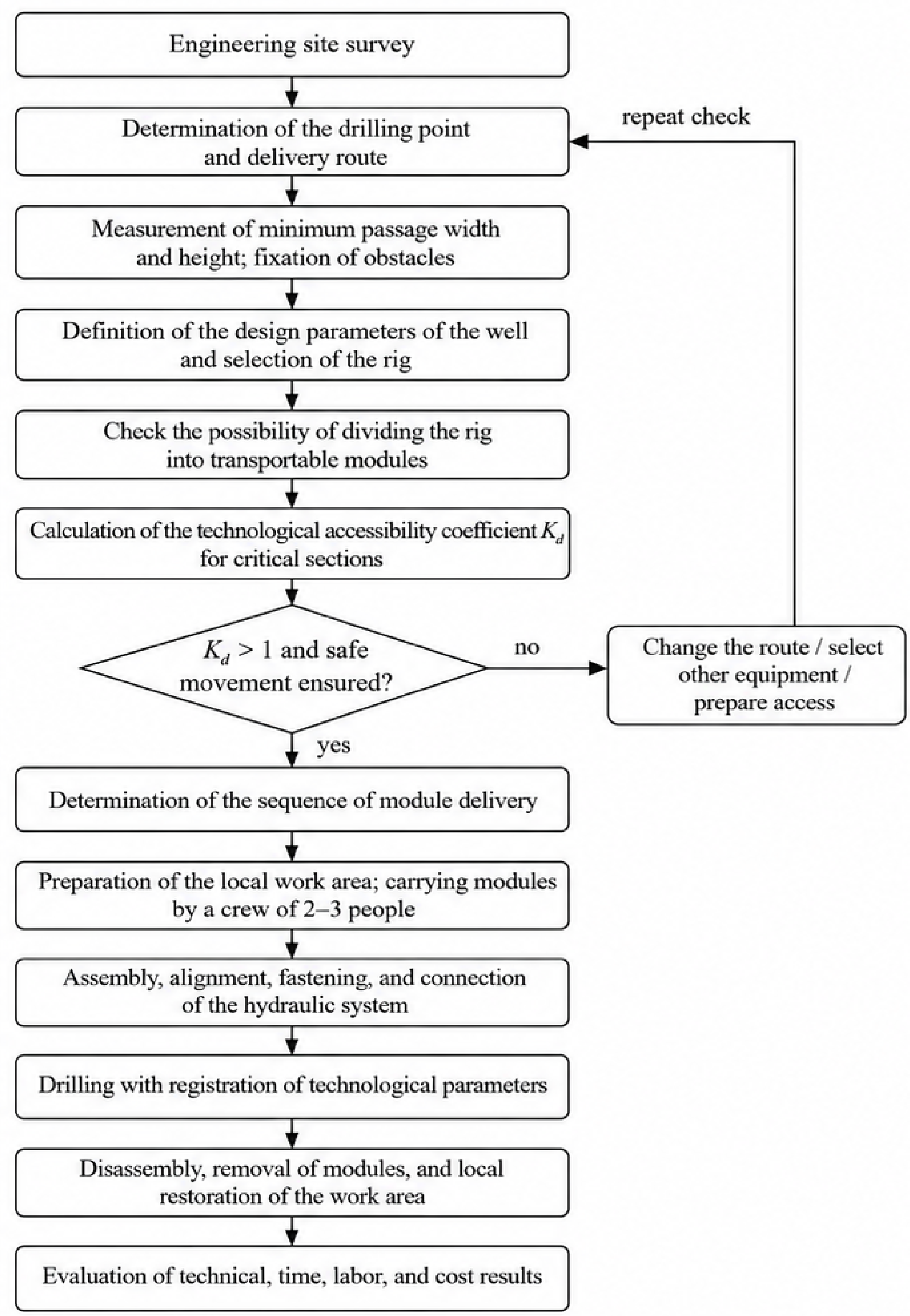

Figure 1. Algorithm for selecting and using a mobile dismountable drilling rig under restricted access conditions

$$E_{40} = \frac{0.40}{1.40} \cdot 100\% = 28.6\%. \quad (11)$$

Thus, 25.9 - 28.6% represents the share of the cost group under consideration in the total cost of the heavy-rig alternative. This range cannot be interpreted as the total saving from using the mobile rig because a final assessment must account for differences in delivery, assembly, labor, fuel or electricity, downtime, and actual productivity.

The total cost model for the two alternatives is written separately:

$$C_A = C_{dr,A} + C_{mob,A} + C_{prep,A} + C_{en,A} + C_{lab,A} + C_{rest,A}, \quad (12)$$

$$C_B = C_{dr,B} + C_{mob,B} + C_{assm,B} + C_{en,B} + C_{lab,B} + C_{rest,B}. \quad (13)$$

The final cost effect, once actual data have been obtained, is determined by the expression:

$$\Delta C = C_A - C_B. \quad (14)$$

The causal relationship between the technical solution and the economic result is shown in Fig. 2. For the heavy machine, the narrow passage creates the need to provide temporary access, perform dismantling, and subsequently restore the site. For the dismountable rig, the narrow section is negotiated by transporting individual modules. Assembly and disassembly therefore appear in the process structure, while a separate group of preparatory operations is eliminated.

The result is consistent with international practice in the use of portable fully hydraulic rigs, where dismountability and low mass of individual components are considered together with productivity and work cost. A distinctive feature of the site examined here is the constraint imposed by existing residential development. Under these conditions, modularity affects whether the technology is feasible even before drilling begins.

Comparative production assessment should account for actual drilling modes. Operation of hydraulic equipment under variable load requires drive parameters to be recorded because rotational speed and load are associated with process stability. At the same time, productivity depends on rock properties, tooling, and borehole-cleaning conditions. Therefore, a shorter drilling time at a single site, without recording the geological conditions, is insufficient to conclude that a particular rig type is superior.

Removal of drilled material is another important aspect. Studies of cuttings transport demonstrate that working-fluid flow rate and rotational speed affect cleaning quality and energy consumption [15]. For a mobile rig, reduced energy consumption should be assessed together with the consistency of cuttings removal because impaired cleaning increases nonproductive time and may offset the expected resource-saving effect.

The proposed approach divides the assessment into three sequential levels:

1. establishes the geometric accessibility of the equipment;
2. confirms the technical compliance of the rig with the design well parameters and drilling conditions;
3. compares the full set of operations, duration, labor input, and costs.

This sequence prevents economic comparison from being performed before the physical feasibility of an alternative has been verified.

The main limitations of the study are related to the available production data. At the time of article preparation, actual well depth, delivery and assembly time studies, penetration rate, fuel or electricity consumption, downtime duration, and the individual mass of each transported component were unavailable.

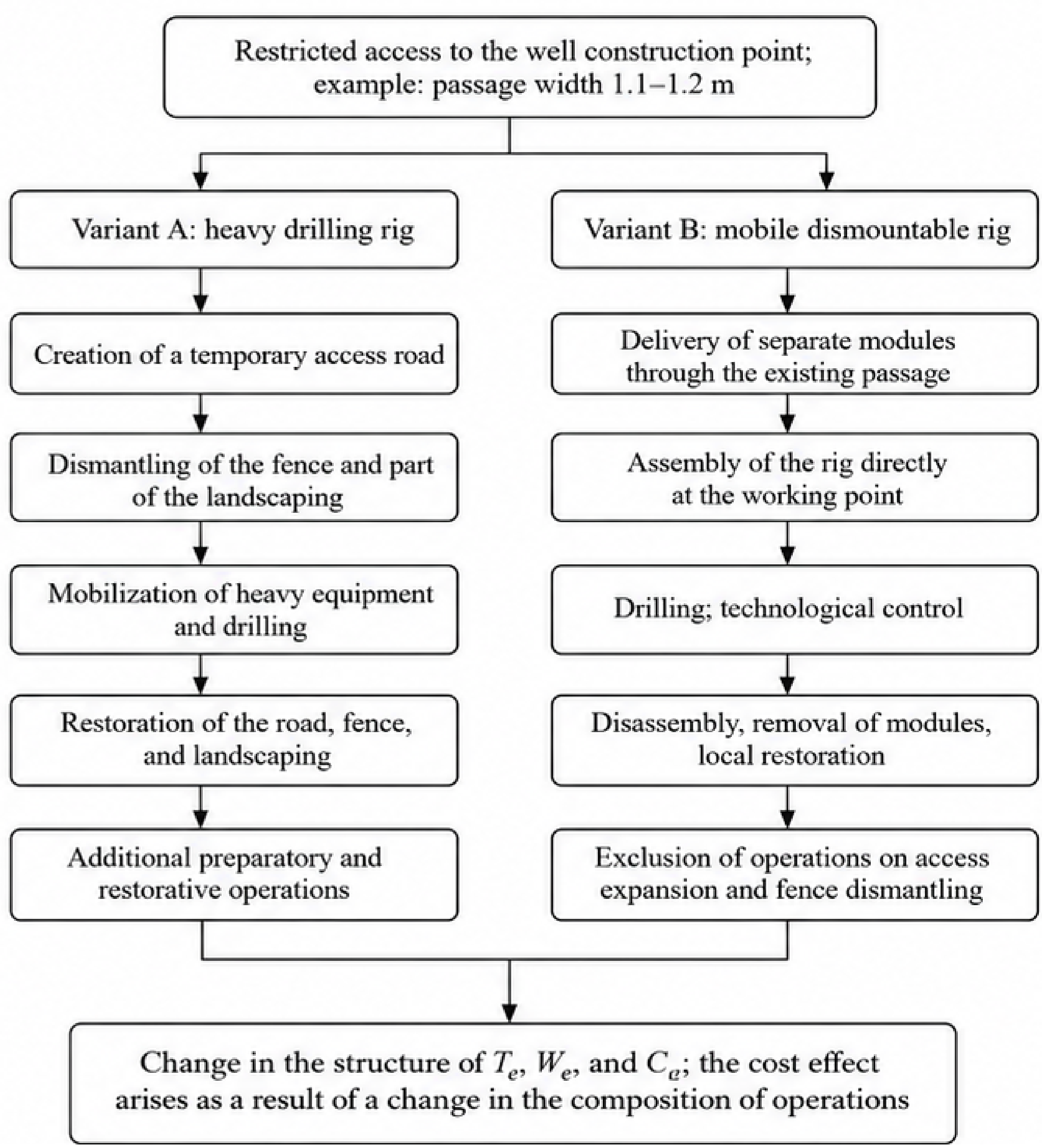

Figure 2. Formation of the technical and production-cost effect of using a dismountable drilling rig

For the final method statement, a module schedule specifying the dimensions and mass of each component must be prepared. The K_a value should then be calculated for each critical route section, and gripping and carrying conditions as well as the ability to negotiate turns should be checked. Production time studies should use the same recording format across several sites. Such a dataset will make it possible to determine stable ranges of assembly and disassembly time, delivery labor input, and actual specific energy consumption.

The main technical result of the practical case is confirmation of the applicability of separating the transport and operating configurations of the equipment. The existing 1.1 - 1.2 m passage is assessed against the dimensions of individual components, while the complete rig is assembled only at the drilling point. This property makes it possible to perform the work without creating a separate access route for a heavy machine.

Conclusion

On a developed site, technological accessibility of the drilling point should be treated as an independent criterion for equipment selection. At the study site, the passage prevented direct access by heavy drilling equipment and would have required modification of the existing site. The study showed that a mobile dismountable hydraulic rig makes it possible to separate the transport and operating configurations of the equipment. The modules are carried by a crew of 2 - 3 people, after which the rig is assembled directly at the work point. For preliminary assessment, the technological accessibility coefficient K_a was proposed. For the known critical module dimension of 630 mm and a minimum passage width of 1100 mm, its value is 1.75; at 1200 mm, it is 1.90. The geometric clearance is 470 - 570 mm. The indicator is intended for preliminary screening and is supplemented by checks of passage height, turns, module mass, and safe handling conditions.

The developed organizational and technological algorithm covers engineering site inspection, route determination, module verification, planning of the delivery sequence, assembly, readiness checks, drilling, disassembly, and performance assessment. It moves verification of technical feasibility to the stage preceding equipment mobilization.

The alternatives should be compared across the full set of operations. For a heavy rig, access preparation and subsequent site restoration become a substantial part of the process, whereas for the mobile rig the role of module handling and assembly/disassembly increases. Duration and labor-input calculations make it possible to include both groups of operations in a unified assessment once time-study data have been obtained.

Eliminating the dismantling of the fence and landscaping elements removes a cost group preliminarily estimated at 35 - 40% of the base project cost. In the total cost of the heavy-rig alternative, this group corresponds to 25.9 - 28.6%. The range characterizes only the effect of access preparation and does not substitute for calculation of total savings.

Further validation should include actual well depth and drilled footage, time studies for delivery, assembly, and disassembly, hydraulic pressure and rotational speed, fuel or electricity consumption, technological stops, and the mass of each module. Accumulating data across a series of sites will enable a transition from engineering justification of applicability to a statistically validated assessment of production and economic efficiency.

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