ITAtech Guidelines On Services Of Machinery For Mechanized Tunnel Excavation

ITAtech Activity Group Excavation

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1.1 FOREWORD

The acquisition and the utilization of a Tunnel Boring Machine is a long process passing through a variety of steps and activities that can last several years in total from TBM design to final tunnel breakthrough. The different activities include design, manufacturing, shop assembly, transport, site assembly, disassembly, maybe reassembly, operational assistance, maintenance & repair, spare parts delivery and general technical assistance. Many of these activities involve Project Owner, Equipment (TBM) manufacturer, Equipment (TBM) user (Contractor) and Equipment (TBM) service provider as well as other specific suppliers.

However, there is a clear line separating this long process in two distinct phases: ex-works delivery will determine the end of the TBM manufacturing phase and the start of TBM Services phase.

TBM Services are preferably provided by the TBM manufacturer but can also be provided by the TBM user itself or other qualified organizations (other TBM service provider).

The purpose of this report is to provide guidance for project owners, designers, TBM users, TBM manufacturers and TBM Service providers when specifying requirements for TBM Services.

1.2 SCOPE

This guideline creates a common language in terms of TBM Services, listing all potential activities that must be scheduled as well as their ideal timing sequence along a tunnelling project. The correct understanding of TBM Services at the start of the project will help project owners, designers and TBM users realize correct planning of the works, evaluating the capacity to cover all activities and eventually take the decision to self-perform or outsource, as the case may be.

Correct planning of the works will minimize both technical and commercial risks for the project, ensuring good coordination between planned activities and budgets and actual work performed.

This report does not cover TBM refurbishment which in some cases may be considered a TBM Service activity. Guidance for this is given in ITAtech Report No 5-V2 “Guidelines on rebuilds of machinery for mechanized tunnel excavation”.

TBM Service activities start after the TBM factory acceptance or ex-works delivery. However, planning and preparation of many service activities must have already started at an earlier stage of the process.

For TBM delivery methods that include only a partial or no assembly and acceptance at the factory the full factory acceptance process has to be performed after the site assembly. Especially the verification of safety requirements and/or protective measures are mandatory. Guidance is given is in EN 16191 (2014) Clause 6 and Annex B.

2.1 TRANSPORT

TBM transport service means the transport of TBM parts (Shield, gantries, additional equipment and materials) from one place to another

- For first assembly: from the place of fabrication to the jobsite assembly location.
- Depending on the project, intermediate transport activities between different locations on site (e.g. shaft or portals) may be required.
- After final dismantling: from the jobsite place of disassembly to the next jobsite, the intermediate storage area, back to a TBM manufacturer´s facility or for scrap and metal recycling.

2.2 PLANNING OF THE WORKS

Planning of site activities such as TBM site assembly, reassembly, disassembly, transfer, and intermediate refurbishment as required. Such planning activities require typically several coordination meetings with all parties involved, starting approx. 6 months prior to the start of the activity, to clarify all technical and logistic aspects, and to ensure that the work is carried out safely, efficiently and within the allotted time schedule.

2.3 JOBSITE ASSEMBLY / REASSEMBLY / DISASSEMBLY / TRANSFER WORKS

Those are the most common service activities related to TBM operation. The level of participation of the TBM manufacturer or other service provider can be different, according to the TBM user's needs or contractual requirements.

Typically, three scenarios are common industry practice, however combined or mixed solutions can also be considered.

• Assistance model:
The TBM manufacturer or other service provider will provide specialized technicians, to guide and advise the TBM user through the TBM assembly process. Provision of all supplies and the management of all activities stays with the TBM user, who is fully responsible for the assembly activities.

• Lump-sum model:
The TBM manufacturer or other service provider leads the site activities through providing a group of specialists and skilled workers, following the planning of the works that he has developed. The TBM user provides support with qualified personnel and jobsite installations (offices, medical facilities, sanitary facilities, temporary structures, scaffolding, access to work zones, concrete cradles or foundations), tools, materials and consumables, general supplies as lightning, electricity, water, compressed air and jobsite equipment (cranes and lifting equipment, cherry pickers, steel cradles). The TBM manufacturer or service provider takes the leadership of the assembly works and the schedule responsibility.

• Turn-key model:
The TBM manufacturer or other service provider is fully responsible of all site activities (engineering, technical, logistic, safety, environment, material and equipment supplies), he receives a dedicated area where he will operate on his own, providing all personnel, equipment and supplies necessary to perform the work, and return back the area after finishing his task.

2.4 MAINTENANCE

TBM maintenance includes all actions necessary to maintain functions and performance of the TBM.

(see also EN 13306: maintenance is the "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function").

2.5 QUALIFICATION OF PERSONNEL

Definition of specialists and qualified personnel typically provided for TBM Service activities:

Senior Engineer / Senior TBM Supervisor:
Experienced technical project manager / engineer or TBM Supervisor with more than 10 years of experience in TBM technology and service. The presence is normally required for complex projects and extended scope service packages (e.g. turn-key model as described in 2.3).

Engineer / TBM supervisor:
Technical project manager / engineer or TBM Supervisor can be required for TBM Services. The presence is normally required for more extended services (duration of 2 month or more) for organizational and management tasks.

TBM Specialist:
Qualified senior technician of more than 3 years of experience with specialist knowledge in a specific field (PLC specialist, hydraulic specialist, main drive specialist, welding supervisor etc.).

TBM Technician:
Qualified technician with general knowledge in a specific field (Hydraulician, Mechanic, Electrician, Fitter, Welder, etc.).

2.6 SUPPLY OF SPARE AND WEAR PARTS

Spare and wear parts are defined as parts (e.g. also called individual components), sub-assemblies (also called assembly groups and component groups) or complete products intended to replace damaged, worn or missing parts, groups or products.

2.7 SUPPLY OF EXCAVATION TOOLS

Excavation tools are special wear parts installed on the cutterhead to fracture / loosen the rock or soil and in case of bucket lips, collect the excavated muck to be conveyed to the primary mucking system of the TBM.

Depending on their design, excavation tools may be single use or have the ability for multiple use after reconditioning (e.g. disc cutters).

2.8 LIFTING WORKS

Lifting works are all lifting activities involved during TBM site assembly, reassembly, disassembly, transfer and necessary to perform the works. Lifting works, as well as the equipment to be used, are defined during the planning phase.

3.1 TRANSPORT

Typically, medium to large size TBMs cannot be broken down into regular small size and weight transport units that do not need special consideration for transport. In addition, the option to transport large size and weight units can significantly reduce the time required for site assembly. Therefore, the TBM transport process should be analysed during the following phases of a project:

Project study phase:
It is very important to start a detailed study of the overall transport process from place of manufacture / shop assembly to the site location at an early stage of the project.

Constraints identified during the project study and listed hereafter can have a significant impact on the TBM design.

Main aspects to be considered are:

- Load capacity of bridges, road, civil structures, etc.
- Maximum height and / or width limitations can by determined by road alignment and fixed obstacles like bridges, buildings, supply lines (power, water, etc.).
- Restrictions due to reduced TBM launching area (shafts, urban contests) and identification of available intermediate storage areas.
- Local traffic restrictions and the possibility for delay in obtaining special permits.
- Local availability of crane sizes for reloading of TBM components (if required).
- Other restrictions (e.g. work restrictions in highly populated or military areas).

Project tender phase:
During the project tender phase, the limitations or constraints identified during the study phase shall be made known to the TBM manufacturer by the TBM user. Based on that information, the TBM manufacturer in the technical proposal can address the specific transport conditions of the project resulting from his concept.

TBM design phase with manufacture :
During this phase all major parts need to be developed and controlled taking account of constraints defined or identified during previous project phases. A preliminary list of the major parts with estimated weight and dimensions should be prepared as the baseline for cost and logistic considerations relating to the transport (cost of transport/ shipping, custom clearance, reloading, transport insurance, etc.).

TBM manufacturing phase:
During this phase the TBM parts have already been designed and all jobsite constraints have been identified. Changes to TBM parts resulting from new transport or storage restrictions may result in additional cost and delays if not identified until the manufacturing phase. The transport will be analysed and planned in detail according to the TBM assembly sequence. Available storage space on site as well as site assembly sequence should be considered as influencing factors. The TBM manufacturer must receive information about how the TBM will be transported and the project time schedule in order to define the most suitable packing sequence for the equipment. Allowance should be made for possible protective measures, particularly for the most sensitive parts and also for temporary intermediate storage of the equipment.

Before / during ex-works delivery, the TBM manufacturer should provide the following services :

- Initial creation of a draft packing / colli list.
- Marking and identification of the TBM parts.
- Packing / protection of the TBM parts.
- Photographic documentation of the TBM parts available on specific request (i.e. in case of damaged parts during transport and related insurance claims).
- Protective measures for sensitive parts (i.e. main drive)
- Lifting points.
- Draft sketches for loading / unloading of the heavy parts (cutterhead, main drive, shield segments, screw conveyor, erector, etc.)
- Possible reduction of the number of component assemblies to minimize transport cost.
- Creation of a final packing / colli list (after loading is completed).

Site arrival:
The following main activities are required:

- Coordination between the different parties involved in the process (TBM user, forwarder, TBM manufacturer or service provider) with day-by-day update of the transport situation and evaluation of eventual interference with other activities.
- Investigation of the unloading area (jobsite or temporary storage) for access, dimensions, suitability of the area (surface load capacity).
- Check if the unloading is done according to the plan taking into account the proper location of the various components at the jobsite. This will avoid unnecessary, double handling of heavy parts.
- Identification of eventual non-conformities when receiving the goods and identification of the causes.
- Check scope between packing / colli list and goods received.
- Implementation of any necessary measures for the protection of the parts during storage (against corrosion, humidity, freezing, dust, UV radiation, atmospheric agents, security).
- Drafting of a final reception report, counter signed by sender and receiver.

A TBM is transported in many shipments, and this increases the possibility that an incident can occur. For this reason, proper insurance against damage or loss of the parts during transport is strongly advised.

3.2 PLANNING OF THE WORKS AT SITE

The planning of the works is an engineering activity that TBM users must develop together with the TBM manufacturer or service provider. Detailed planning of the site activities related to TBM assembly is of major importance for work safety, economy and schedule.

Within that planning activity the following aspects are typically analysed and performed:

- Detection of potential restrictions or interference with the surroundings (e.g. noise restrictions, community restrictions in highly populated areas, presence of sensitive areas such as airports and military zones, lack of space for jobsite set-up, etc.).
- Determination of final schedule after evaluation of alternative schedules for accomplishing the objective.
- Determination of lifting equipment (cranes, vehicles, special equipment) and their positioning.
- Position of all TBM parts / equipment to be assembled / disassembled / installed / moved.
- Sequence of the works after technical feasibility has been proven (2D-3D drawings).
- Personnel plan according to the agreed sequence of the works and consideration of local regulations on working hours.
- List of standard or special tools required as well as any other equipment needed.
- Detailed time schedule covering all operations and activities.
- Definition of responsibilities and required qualifications.
- Documentation required for the site activities such as method statements, risk analysis, working procedures, safety training and inductions, work permits etc., based on user / jobsite and/or local rules and regulations.

The correct planning of the works will be the basis on which to take all decisions on how the works will be executed, it will allow a proper estimation of schedule and cost and it will be used during site activities as a reference to check the progress of the works.

3.3 EXECUTION OF THE WORKS AT SITE

The TBM manufacturer or service provider involved in this phase should coordinate with the TBM user to achieve all necessary deadlines in time to allow the correct start and further development of the site activities, as planned.

The pre-requirements are:

- The start date for the relevant activity should be defined.
- The scope of each party involved should be defined.
- The shift models are agreed.
- The jobsite set-up should be prepared as planned (civil works, facilities, plants, operating materials, power supply, etc.).
- All lifting equipment, jobsite vehicles, materials, equipment, tools should be available when required.
- All logistics relating to personnel deployment should be prepared.
- All requirements (in terms of safety inductions, papers and documents) for working personnel are clear and the information has been distributed.
- All requirements (in terms of procedures, method statements, static calculations) for the achievement of the site activities are available.
- Contracts with external companies providing supplementary services are in place (scaffolding, cranes, equipment certifications, etc.).

3.4 MAINTENANCE

3.4.1 General

Equipment maintenance is one of the key elements for the safety and the technical as well as commercial success of a TBM tunnelling project. In addition, planned maintenance enables meeting the schedule, as equipment problems are more likely to be avoided or identified in advance, thus making necessary repair works less likely or at least more predictable and enabling the ordering of spare parts in due time. A well-organized maintenance program typically results in more constant and predictable production (advance) of the tunnelling equipment.

Typically, all maintenance requirements are given by the manufacturer in the TBM handbook for safe operation and in order to achieve specific guarantees or buyback obligations agreed in the equipment supply contract.

However, different maintenance strategies may be used in practice depending on the decision or company philosophy of the TBM user.

The choice of a maintenance strategy is primarily based on the risk of failure. The failure risk, in turn, depends on the frequency of failure and the severity of damage caused by it.

Maintenance strategies should be only selected based on in-depth knowledge of the equipment and its behaviour during operation. For complex tunnelling equipment the preferred solution should be the involvement of the TBM manufacturer in planning and execution of maintenance works and programs.

A qualified third-party service provider, experienced in specific TBM technology, may be an option so long as they are given access to the full technical documentation for the equipment by the TBM user. Potential interference with warranty or the buy-back conditions set by the TBM manufacturer, need to be checked in detail.

3.4.2 Maintenance strategy

Which strategy is used and when depends on several factors or combinations thereof:

- Project risk
- Project duration
- Project size
- Project volume
- Personnel qualifications and technical possibilities
- TBM user philosophy or company guidelines

The choice of the maintenance strategy for a project can result in a major impact on both project duration and overall project result.

Predetermined maintenance
Predetermined maintenance is scheduled, preventive maintenance "carried out in accordance with established intervals of time or number of units of use but without previous condition investigation".

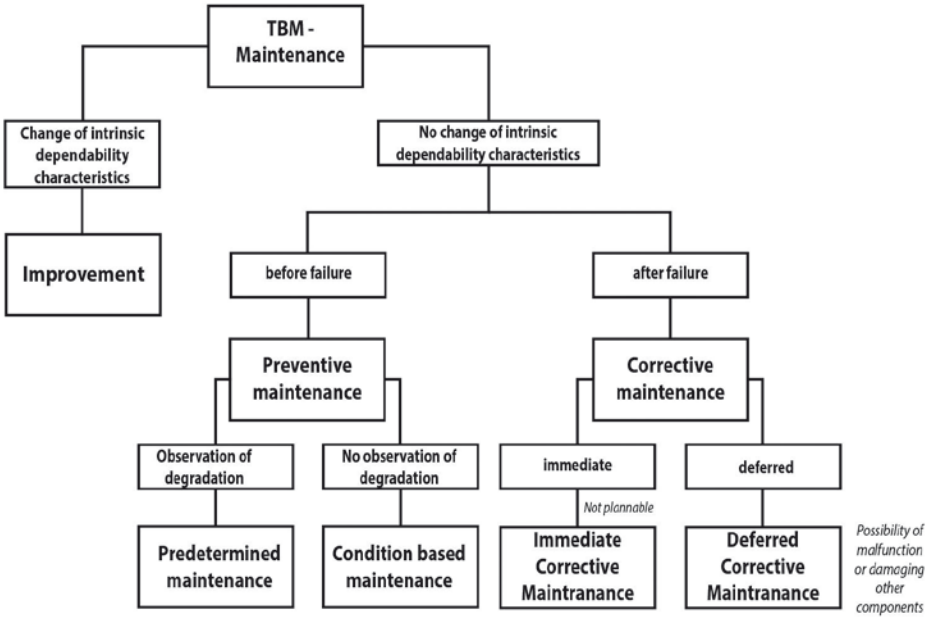
In this case the lifetime of a component is decided by reaching a certain value of a certain unit (time, volume, metres, excavated rings), and the accuracy of this prediction depends on the experience of the TBM manufacturer.

A typical example of predetermined maintenance is oil change intervals (hydraulic oil, gear oil) after reaching a certain number of operating hours independent of its physical status.

Condition based maintenance
It is preventive maintenance "which includes assessment of physical conditions, analysis and the possible ensuing maintenance actions".

Components or elements are replaced when a certain wear and tear amount or a defined usage limit is reached. The condition assessment may be done by a visual inspection or testing and does require detailed inspection procedures and / or specifically experienced personnel. Frequent inspection and testing should be combined with an appropriate documentation system to allow for wear prediction and planning of maintenance requirements.

Condition monitoring systems based on sensor readings connected to the TBM data recording and data evaluation software can provide additional complementary measures or in some cases replace the need for inspection and testing by automatically indicating the predicted requirement for maintenance or exchange to the TBM user. Alarms or even interlocks are possible at certain trigger values to avoid subsequent equipment damage.



Different maintenance strategies according to EN 13306

Immediate corrective maintenance
This is damage-oriented maintenance "carried out after a fault has been recognized and intended to restore an item into a state in which it can perform a required function".

This approach is not acceptable for safety relevant parts or functions. It may also imply a certain technical risk since some components, when failing, can damage other elements of the system that finally can result in significant equipment damage and long TBM stoppages.

3.4.3 Maintenance organization

Numerous functions or elements on a TBM can only be maintained during standstill or non-mining mode. Considering that a modern TBM can be compared to an underground factory with a high number of interdependent processes and activities, lack of maintenance can cause frequent and unplanned stoppages of the entire tunnel production chain.

Since many tunnelling projects are three shift – seven-day operations, maintenance activities must be scheduled in a way to minimize interference with TBM advance.

Maintenance during TBM advance
Activities like visual inspection, monitoring, adjusting, cleaning, filter check, fill level, fluid pressure and temperature check, greasing, can be normally done during TBM advance. They should be performed by each working shift based on the maintenance plan for the TBM.

Maintenance during TBM stoppage
When a TBM stoppage is planned, there is the possibility to plan and perform in parallel, longer maintenance works to equipment which would normally require the TBM to stop (e.g. segment crane, segment feeder, erector, tail skin brushes, grouting pumps and lines etc.).

Planned TBM stoppages can be due to:

- Cutterhead maintenance.
- Service extensions such as pipes, tunnel belt conveyor, high voltage cable, ventilation duct.
- Surface, shaft or rear tunnel works interfering with the TBM advance like for example booster pump or California switch installation.
- Shift models that include planned non-mining shifts.

General preparation for maintenance activities

To ensure efficient, high quality and safe maintenance operation without additional delay the activities must be prepared in advance in order to identify and make available the necessary information and materials. Every maintenance activity requires preparation.

The following questions should be answered before starting a maintenance activity:

- Are spare parts required? If so, which ones? Order spare parts in time.
- Are consumables required? If so, which ones? Order consumables in time.
- Which tools are required? Get / prepare the right tools for maintenance.
- Will the operation of the TBM be affected? If necessary, schedule planned downtimes.
- What skills/qualifications are required? Organize maintenance teams according to qualifications required.
- Is a work guideline / description of the work available? Recommended for all tasks.
- Who will be in charge of the proper reporting of the activities done ?

3.5 SUPPLY OF SPARE AND WEAR PARTS

For a TBM user, the reliable provision of spare and wear parts at the right time, in the corresponding quantity, type and quality is the basis for high TBM availability and performance.

The first batch of spare parts should be available on site at the latest by the time the TBM starts excavation.

The spare and wear parts provided should be as per the TBM manufacturer specification, in order to ensure the correct function of the equipment and avoid warranty problems. Especially for safety relevant parts, this is of major importance.

The planning of spare parts supply is of crucial importance for the success of the project, and can be divided in the following steps:

- Generate a spare and wear part list from the TBM manufacturer, according to his experience in similar projects, with an indication of number and expected delivery times.
- Definition of a consignment stock from the TBM manufacturer, if agreed, for "show-stoppers" - some key parts which the TBM manufacturer can agree to keep available for the project in his storage facilities.
- Definition of the protocol for spare and wear part delivery.
- Follow-up of the inventory of the spare and wear parts consumption during TBM advance.

3.5.1 Supply logistics of spare and wear parts

Transportation of spare and wear parts between the TBM manufacturer´s warehouse and jobsite should be organized on time and considering all regulations between the countries of origin and country of destination. All necessary documentation needs to be prepared by the TBM supplier in order to avoid delays for custom clearance etc.

Delivery times for spare and wear parts can vary significantly. The main factors influencing the availability of a part at a certain time are normally:

- The value of the part: the higher the value, the lower the stock at TBM manufacturer or part supplier.
- The demand frequency of the part (parts with a high frequency of demand or high wear rate have typically a better availability due to higher stock volumes at the manufacturer's facility).
- The global request and the time needed to produce the parts: this is the most unpredictable factor, as high demand of parts and problem in parts production can lead to extended delivery times.

The TBM manufacturer should assign expected delivery time for each spare and wear part and advise the TBM user on recommended jobsite stock volume.

3.6 EXCAVATION TOOLS

3.6.1 General

Correct estimation of the consumption of excavation tools is a major element for a tunnelling project to stay within schedule and budget. The anticipated excavation tool consumption depends strongly on the knowledge of the predicted subsurface conditions and the accuracy of the prediction models. However operational aspects and individual excavation tool maintenance strategies can also have a significant influence.

A large variety of excavation tools for hard rock as well as for soft ground is available either from TBM manufacturers or excavation tool suppliers. The better the knowledge about the expected ground conditions the better the selection of an efficient excavation tool dress for the cutterhead can be achieved during the TBM design phase.

Empirical data, past project experience, individual TBM manufacturer and user know-how as well as theoretical prediction models typically form the basis for the specific excavation tool configuration. However, in many cases excavation tool modifications or excavation tool set variants are tested and applied along the project in order to optimize excavation tool performance and adapt to the real experienced ground conditions.

3.6.2 Requirements for excavation tool suppliers

The design and selection of excavation tools requires specific knowledge. Besides the excavation tool technology itself it is essential to understand the cutterhead design and all related operational aspects and possibilities for the excavation process (e.g. cutterhead thrust and drive parameters, soil conditioning system, slurry circuit, mucking system etc.). Therefore, preferably the TBM manufacturer should be involved in the process of excavation tool selection.

As a minimum the excavation tool supplier should meet the following requirements:

- Specific know how in excavation tool engineering and metallurgy for competent advice.
- Extensive knowledge of the different excavation tool behaviours in the predicted or existing ground conditions, with different cutterhead designs and with different excavation parameters and conditions.
- Availability of experienced excavation tool service personnel for technical support.

- Extended records of data coming from previous projects to be used as reference.
- Extended product portfolio, to guarantee the use of the most suitable solution for a given situation, and customized excavation tools for single scenario situations.
- Knowledge of the interaction between excavation tools, tool fixation elements and cutterhead structure.
- Knowledge of the TBM operational aspects related to the excavation process.
- High quality standard for manufacturing excavation tools.
- Adequate manufacturing capacity to fulfil the anticipated demand / delivery time.

3.6.3 On-site availability of excavation tools

Starter kit excavation tools

TBM users should store a certain quantity of excavation tools on site before the start of the TBM excavation. The starter kit should include all necessary excavation tools expected to be replaced within the delivery time for further excavation tools (supplier information). The initial starter kit should reflect the expected wear and consider the possibility of unexpected events which could occur during the TBM start-up (e.g. shaft wall crossing).

The starter kit decreases the risk of a TBM standstill and gives time for the TBM user to make further considerations about the excavation tool selection or optimization after the first stretch of tunnel has been excavated.

Circulation set

For excavation tools that provide a multiple use option with intermediate reconditioning (disc cutters) a certain quantity for circulating between use and reconditioning is required. The definition of the circulation set quantity is based on the anticipated disc cutter consumption and the organization of the reconditioning process (on-site or off-site, required transportation time, working shift patterns, reconditioning capacity etc.) This quantity also should include a number of disc cutters to cover contingencies. The higher the number of disc cutters in the circulation set, the lower the risk of running out of disc cutters and of having a subsequent TBM standstill.

3.6.4 On-site reconditioning of excavation tools

On site reconditioning of multiple use excavation tools, predominately disc cutters, is a common practice in hard rock tunnelling. Depending on the expected consumption, it can be reasonable to install a disc cutter reconditioning workshop (cutter shop) on site. The cutter shop allows the full reconditioning of disc cutters. The size and capacity of the cutter shop is related to the expected disc cutter consumption. For low to medium capacity, readily installed containerized versions are available from most of the manufacturers, for higher capacity real workshop installation including a disc cutter parts storage area may be the recommended solution. Since disc cutters are supplier-specific designs, the inventory of equipment and special tools in a cutter shop must be coordinated and agreed with the excavation tool supplier.

Depending on the individual supply or service contract on-site, disc cutter reconditioning may be the sole responsibility of the excavation tool supplier but other arrangements such as the excavation tool supplier providing supervision only or the user taking full responsibility for disc cutter reconditioning are common practice in the industry. However, it is vital that all personnel engaged in disc cutter reconditioning are well trained by the excavation tool supplier for the specific excavation tool types.

Independent of the organization and responsibility for disc cutter reconditioning, clear documentation of all disc cutter reconditioning steps is recommended to achieve a full life cycle history of each disc cutter. Such documentation is considered one of the key tools for quality control and for optimizing disc cutter cost. Most excavation tool or TBM suppliers offer individual TBM-specific documentation software.

3.6.5 Off-site reconditioning of excavation tools

Depending on the quantity of disc cutters to be reconditioned and the individual contractual arrangements, the site location and related transport costs, off-site disc cutter reconditioning may be a reasonable solution. Typically, such reconditioning is under the full responsibility of the TBM manufacturer or excavation tool supplier in his own facility.

The advantages of such an arrangement are:

- No investment costs for workshop & warehouse installation for TBM user;
- No costs for disc cutter reconditioning specialists on site;
- Direct inspection, documentation and data interpretation of the disc cutters by the excavation tools supplier;
- Full excavation tool supplier's responsibility for the quality of the reconditioning works, and short reaction time for technical optimization.

3.6.6 Excavation tools - stock keeping

Stock keeping management is an important element to ensure availability of excavation tools and excavation tool components when needed. Especially in light of the fact that many of the components are custom made long lead items, a well-planned inventory ensures an undisturbed tunnelling operation.

TBM manufacturers and excavation tool suppliers may, depending on contractual arrangements, offer assistance or even complete stock keeping solutions.

3.6.7 Excavation tool consumption data management

Detailed documentation of the TBM excavation tool condition and replacement (consumption) per excavated unit is of utmost importance for all subsequent planning tasks aimed at optimizing TBM production and for planning future excavation tool demand.

Typical information to be collected with a high degree of accuracy during excavation tool inspection and replacement are:

- Time and position (e.g. tunnel station) of cutterhead inspection and excavation tool replacement.
- Position on cutterhead (track) and excavation tool condition for tools replaced.
- Position on cutterhead (track) and excavation tool condition for tools inspected.
- Condition of disc cutter fixtures (cutter housings, tool sockets etc.) for tools replaced or inspected.

- Condition of the fixed (welded) wear protection.
- Condition of the cutterhead structure.

Excavation tool condition to be documented:

- Amount of wear (special measurement devices may be required for different excavation tool types).
- Nature, type of wear or wear pattern.
- Type and shape of mechanical damage if detected.
- Any sort of malfunction if detected.

The in-situ ground or rock conditions experienced, the TBM operational parameters from the data recording system and the data collected on disc cutter tools are the key sets of information for optimizing the TBM operation. This may include modifying and adjusting the predictions for excavation tool consumption.

Most TBM manufacturers offer specific documentation and reporting software for individual TBMs that can be combined with the TBM data recording system.

Excavation tool specialist support services for data evaluation and operational optimization are available from most TBM manufacturers.

3.7 LIFTING WORKS

3.7.1 General

As the components are often large in weight and dimension, specialist equipment and staff needs to be recruited for lifting works. This might as well require special structural provisions to allow access and give stability to the equipment during all phases.

3.7.2 Preliminary lifting studies

Lifting works should be analysed at an early stage. Constraints in the jobsite assembly / reassembly / disassembly areas can have an impact on the final TBM design.

Evaluations to be done are:

- Definition of TBM assembly sequence (i.e. Planning of the works).
- Definition of lifting equipment and maximum lifting capacity.
- Definition TBM assembly place, including required weight/load capacity.
- Assembly area accessibility.
- Space available for crane positioning and initial TBM parts storage.
- Local availability of lifting equipment.
- Maximum lifting capacities on jobsite or storage area.
- Other restrictions (e.g. height of cranes near or at Airports, presence of overhead power lines).
- Possibility for further use of the lifting equipment during TBM operation (e.g. gantry crane for TBM / gantries assembly for segments / materials handling).
- Definition of activities necessary to achieve the lifting works (surface preparation, welding of lifting lugs, etc.).

If any specific constraint limits the maximum lifting capacity or dimensions of assemblies to be lifted, the TBM manufacturer must be given this information in the early stage of the TBM design.

Lifting activities, especially for heavy loads, require dedicated studies which should be carried out by the TBM user in cooperation with the lifting service and equipment provider and the TBM manufacturer. Depending on the site condition these studies can be rather complex and may require a significant effort which should be allowed for in budget and schedule.

3.7.3 Site activities

Prior to starting site activities, all preliminary study results concerning lifting activities must be included in the TBM assembly procedures / method statement. The document is the base for site inductions for the working personnel.

The lifting service and equipment provider must be made aware of all details and planning related to his service.

The handling of heavy parts is a safety critical issue and all procedures must be checked by the safety officers in charge. Local rules and regulations may require further specific planning and documentation.

4.1 BUSINESS MODELS FOR SITE ACTIVITIES - PERSONNEL

TBM manufacturers and other TBM service providers can assist with services based on different business models which can be customized, depending on the TBM user´s requirements. Three typical common-used practices are listed. Variations or mixed solutions may also be considered for individual projects.

Assistance model
The TBM manufacturer or TBM service provider will assist the TBM user with specialists and provide support on how to perform the activities related to the TBM and related equipment (assembly / reassembly / disassembly).

The TBM manufacturer or TBM service provider is not in charge of the jobsite activities and is not in charge of the overall process. The qualified personnel supplied are working under the control of the TBM user. Their number depends on factors such as on-site condition, size and type of TBM and shift pattern. The TBM user is responsible for achieving the targets for the site activities in terms of safety, schedule and budget.

A typical scope for assistance contains a minimum number of five specialists (Engineer, TBM or Mechanical Supervisor, Hydraulic Specialist, Electrical Supervisor or PLC Electrician, Welding Supervisor). Nevertheless, the number of specialists depends on the TBM user's abilities, site condition, size and type of the TBM and shift model used.

Lump Sum model
The TBM manufacturer or TBM service provider will propose to the TBM user the daily program according to the agreed sequence of activities, in order to perform the works in the planned time. He will direct the site activities with a group of specialists and skilled workers. Their number depends on factors such as on-site condition, size and type of TBM and shift pattern. He will organize work teams including supporting workforce made available by the TBM user. He will request in advance materials and equipment needed for the site activities.

The TBM manufacturer or TBM service provider has the responsibility for achieving the targets, but the TBM user must provide all agreed support and milestones on time and with agreed quality (qualification of jobsite personnel, compliance with the instructions received, quality of the materials, supplies, equipment as per requirements, provision of the civil works and of any additional activities required on time and according to the agreed plans, etc.)

This service is offered as a lump-sum. The number of specialists and skilled workers supplied by the TBM Manufacturer or the TBM service provider must be sufficient to direct and control the site activities. A clear definition of the qualifications of the supporting workforce, made available by the TBM user, must be agreed between the TBM manufacturer or service provider and the TBM user. A process to resolve potential disputes about level of qualifications should be part of the service contract.

Turn-key model
The TBM manufacturer or TBM service provider manages all assembly activities, according to local rules and regulations. He will provide all materials, consumables, equipment and manpower needed for the completion of the works. He will send informative reports on the progress of the works to the TBM user and is responsible for achieving targets and agreed performance. As required, he will employ sub-contractors and consultants to handle the overall activities.

Whichever is the chosen business model, the TBM manufacturer or the TBM service provider should be able to prove his capability to provide the personnel profiled in chapter 2.5.

	JOBSITE ASSEMBLY	TEST RUN	EXCAVATION	DISASSEMBLY	FINAL PACKING
1x Engineer	2,5-3,5 months	2 weeks	If required	1,5 - 2,5 months	-
1x TBM Supervisor	2,5-3,5 months	-	If required	1,5 - 2,5 months	2 weeks
1x assembly Supervisor	2,5-3,5 months	-	If required	1,5 - 2,5 months	-
1x Electrical Supervisor /PLC	2 Months	2 weeks	If required	2 weeks	-
1x PLC Electrician	-	2 weeks	Recommended	-	-
1x Main Drive Supervisor	2 weeks	-	-	-	-
2x Welding Supervisor	6 weeks	-	-	3-4 weeks	-
Welders	If required	-	-	If required	-
1x Hydraulic Supervisor	-	2 weeks	-	-	-
1x TBM mechanic	2,5-3,5 months	If required	Recommended	1,5 - 2,5 months	2 weeks
2x TBM electrician	3 weeks	2 weeks	Recommended	If required	-
2x Fitter	2,5-3,5 months	-	-	If required	2 weeks
TBM operator	-	-	If required	-	-
Erector operator	-	-	If required	-	-
1x TBM Safety inspector	-	1 week	-	-	-

Table 1

The business model chosen, and so the number of specialists required depends mainly on the following aspects :

- Overall ability and resources of the TBM user
- Available budget
- Risk Management
- Project time schedule
- Project complexity
- Shift pattern

Considering a standard TBM assembly of approximately 3 months duration, the table 1 shows as an example, a general personnel - time schedule, indicating the personnel and their skillset required for each step in the project and the expected duration of their working period.

4.2 BUSINESS MODELS FOR SPARE PARTS CONTRACTS

Spare parts supply can be included with the business models:

- Procurement of parts
- Consignment contract
- Unit-based contract

4.2.1 Procurement of parts

A list of recommended spare parts is typically agreed between the TBM manufacturer and the TBM user, however spare parts management is the full responsibility of the TBM user (e.g. appropriateness of storage conditions, inventory, purchase). Transport of the parts can be organized by the spare parts supplier or by the TBM user.

4.2.2 Consignment contract

A consignment contract between TBM user and manufacturer establishes a volume (contract value) of parts that will be stored by the TBM manufacturer to ensure their immediate availability for the project. The contract value depends on the TBM type and diameter. The relevant list of parts is agreed between the TBM manufacturer and the TBM user.

The TBM user will pay an agreed interest rate based on the consignment contract value, the ownership of the consignment stock content stays with the TBM manufacturer. The TBM user will be invoiced for an individual part when taken from the consignment stock.

The management of the consignment stock (on site storage facilities and inventory) is the responsibility of the TBM user, however individual project specific agreements are possible between TBM user and TBM manufacturer.

Typically, project-specific major spare parts (e.g. main bearing, thrust cylinders, etc.) and wear parts (e.g. excavation tools) are not part of the consignment stock.

4.2.3 Unit based contract

With a spare part unit-based contract between TBM user and TBM manufacturer, the TBM manufacturer has to supply all agreed spare parts as required.

Payment for the spare parts will be based on a fixed rate per unit (linear metre or cubic metre) that is agreed between the TBM user and TBM manufacturer, based on the individual project conditions.

Individual contract mechanisms for rate adjustments based on “as experienced” conditions throughout the life of the project are normally included in such contracts.

4.3 BUSINESS MODEL FOR EXCAVATION TOOL CONTRACTS

Excavation tools supply can be included with the business models :

- Procurement of excavation tools
- Disc cutter reconditioning contract based on actual parts consumption
- Disc cutter reconditioning contract unit-based

4.3.1 Procurement of parts

In this case complete excavation tools, disc cutters or parts necessary for their reconditioning are purchased by the TBM user as normal spare and wear parts. The reconditioning of disc cutters is done on- or off-site by the TBM user, with or without supervision from the excavation tool supplier.

4.3.2 Disc cutter reconditioning contract based on actual consumption of parts

When the expected disc cutters consumption is low, the TBM user might chose to request an on- or an off-site disc cutter reconditioning service from the excavation tools supplier (see par. 3.6.4 and 3.6.5) and so bear the costs of the parts necessary for reconditioning the disc cutters plus a lump sum for the works executed.

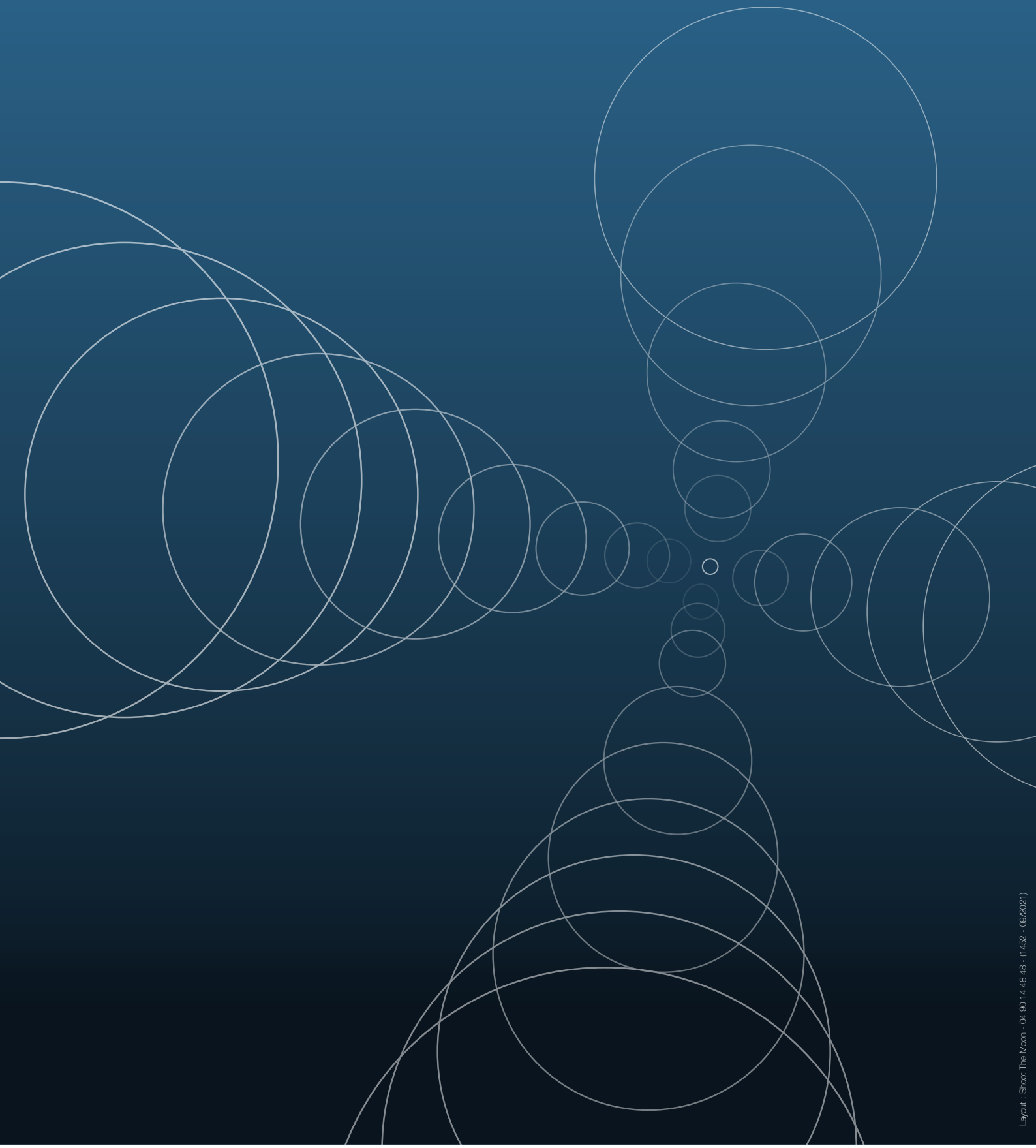
4.3.3 Unit based contract

When a unit-based contract between TBM user and excavation tools manufacturer is established, the excavation tools supplier has to provide all excavation tools including those which are repairable or not (disc cutters, scrapers, bucket lips, etc.).

Within the contract agreement, the TBM user and the excavation tools supplier will specify whether or not disc cutter reconditioning is done on- or an off-site.

Payment for the excavation tools provided, will be based on a fixed rate per unit (linear metre or cubic metre) that is agreed between the TBM user and excavation tools supplier, based on the individual project conditions.

Individual contract mechanisms for rate adjustments based on “as experienced” conditions during the life of the project are normally included in such contracts.



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