THE GOVERNANCE OF COST IN TUNNEL DESIGN AND CONSTRUCTION

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Abstract - The governance of cost in design and construction of underground infrastructure projects are of paramount importance. To ensure cost and project delivery schedule requirements and to promote safety, quality and functionality of the underground facilities this needs to be continuously analysed.

Often it is not realized that underground construction project delivery even under the tested and proven conservative approach represents formidable challenges in terms of delivering the underground facility projects on time and within budget and in meeting all of the project requirements of safety and quality.

A lot has been focused in the industry on the shifting of the risk to the contractor and on legalistic aspects of the contract documents. The physical nature of underground works, and the associated challenges with underground design and construction has not been fully appreciated. It is not sufficient only to extrapolate the above-ground infrastructure experience to underground construction. The features of underground design and construction procurement must be efficiently fused into the overall procurement.

Keywords - Design / Build Contract, Design / Bid / Build Contract, Conventional Tunnelling, Mechanized Tunnelling, Risk Management, Risk Sharing.

INTRODUCTION

Underground projects and mostly public transportation projects require major financial investments. For reasons of successful investment construction costs estimates need to be combined with phased risk analysis. An unrealistic cost estimate can prepare the path for project failure in the early phase. The public sector faces major problems to finance such projects due to budget and time constraints.

In order to realize successful project implementation there is a need to carefully examine schedule prolongation. This risk can be reduced by reducing the time necessary for financing. Financial problems of schedule slippage can be controlled in such projects by using as a contract model "private-public-partnership (PPP)", whereas project financing comes from private financial institutes. Such institutes may be represented by individuals or by bank consortia who are interested to put funds on the market provided that a defined risk is covered by the public sector, and whereas other risks are covered by the private sector. This allows for the investment of capital over a longer period of time.

The prerequisite for successful investment is represented by reliable cost estimate for construction and related project costs. Underestimated construction costs principally do cause sincere problems such leading to the risk of project. There are mostly more than one reason for underestimating real project cost. The cost estimator may know constraint budget conditions, such trying to make his cost estimate fit into the public clients budget.

At the same time this may be misleading him in recognition of specific cost influences. At the moment of bid opening this may result in coalition between the original cost estimate and the market response, such creating the risk of project failure.

In order to reduce the risk of unrealistic cost estimate it is recommended to investigate both the overall cost of comparable projects and to examine the cost composition of such comparable data. The evaluation of other cost estimate and respective construction culture should result in reliable figures whereas it is recommended to use the dynamic risk analysis approach as a link between cost estimate and bid price from the beginning via bidding until the end of construction.

EVALUATION OF TECHNOLOGY

There were essentially two, seemingly different tunnelling schools, which could be clearly distinguished from one another both in their application areas and in terms of cost. Alpine mountain tunnelling in rock was a domain of the "New Austrian Tunnelling Method" (NATM). By contrary, the construction of inner-urban traffic tunnels- where soft ground and ground water presents major influencing factors, as does the presence of surface structures, was essentially reserved for the shielded "Tunnel Boring Machines" (TBM), i.e. driving with precast tunnel lining systems.

NATM and TBM have been fundamentally differing competing technologies in the underground environment. NATM technology is coming from the geomechanic understanding of the interface condition & is aiming towards industrialized and thus highly mechanized tunnel production with less consideration of the interaction between excavation and geomechanical response. Experiences of the mining industry required preservation of three dimensional stress conditions in the underground to the maximum extend. The state of the art of mining technology, where all tunnel

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technology comes from, was waiting for new findings in regard to the interactive behaviour between soils, rock and water.

Parallel to the development of mechanized tunnelling with shielded equipment, the development of the use of gunite, later called shotcrete, started at the turn of this century. By the nature of shotcrete, and its strength development as a time dependent process, it was necessary to consider the geomechanical behaviour of the surrounding underground into more details. Because of this fact, and because of the non-existing temporary and protecting steel cylinder, the use of shotcrete has so far been limited to self standing rock conditions.

Conventional Tunnelling Technology

Conventional Tunnelling, widely named NATM started its development in hard rock. Economically it could compete later against TBM's in soft ground, because of its incorporation of geotechnique. TBM's became more and more mechanized, and even stronger with regard to their installed power. TBM manufacturers understood, that NATM construction time wise and tunnel lengthwise was not competitive with hard rock tunnelling machines, and therefore hard rock became the domain of TBM's. The need for mass transit, mostly in soft ground in densely populated urban areas, - most of them located in alluvial deposits with rivers or near lakes-, created the need for public transportation. At least within the cities it was mostly impossible to avoid tunnelling underneath existing buildings. Requirements with regards to settlements became more and more strict.

Starting with single track tunnels, good results with regard to stability and settlements encouraged respective NATM designer to enlarge cross sections further, and to improve project economy for the client at the same time. Double track tunnels have been following single track tunnels, and stations have been following double track tunnels. With multiple drift methods it looks, that there are almost no limits for further enlargement.

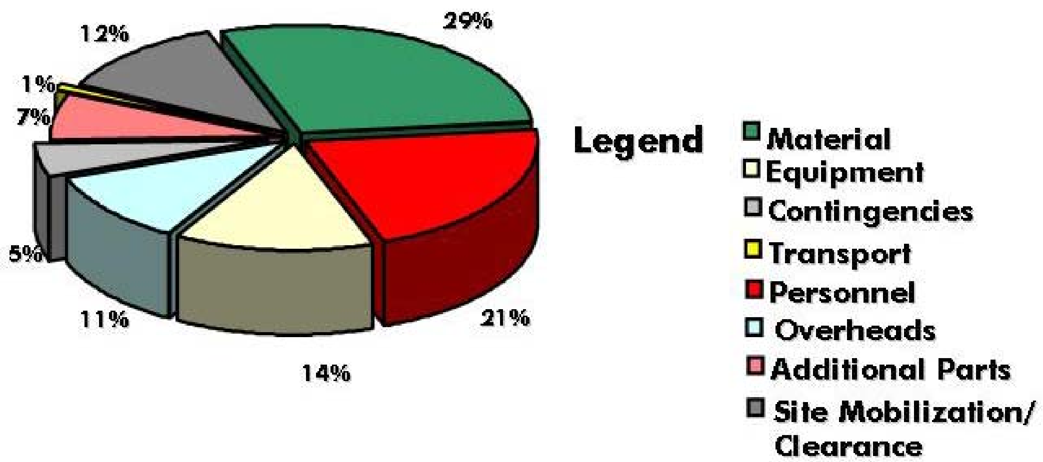

Fig. 1 Typical Cost Distribution – Conventional Tunnelling
(Example of metro tunnel in soft ground)

Mechanized Tunnelling Technology

Shield tunnelling technology started under soft ground conditions. The shield itself contains a cutter wheel at the face, and a segment erector in the rear. Soils typically moved onto the shield skin, thus giving close contact through its deformation behaviour between the underground and the temporary support, of the steel shield. The segments are erected in the shield tail area while the shield is pushed forward by hydraulic jacks resting on the segmented lining.

When rock tunnels have been excavated with tunnel boring machines in the past, such machines typically consisted of a cutter wheel with disk or teeth cutters, and with two pairs of grippers thirsted against the rock, to move the machine forward.

In the course of further development of tunnelling technology such machines became not only used under hard rock conditions, where no rock support was require, but also under conditions, where hard rock and soft rock, or sometimes faulted geology, alternated. As soft rock tended to deform into the inside of the tunnel, and sometimes was even dangerously unstable, it became necessary to install temporary and/or final support.

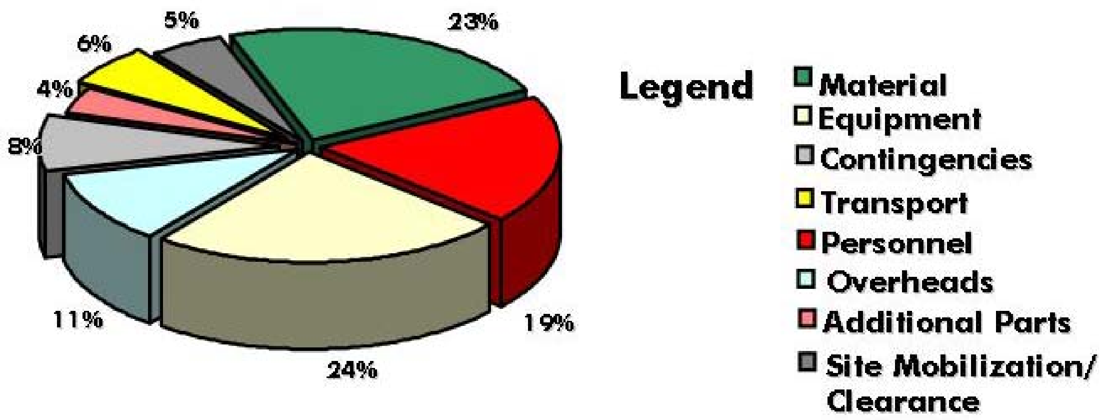

Fig. 2 Typical Cost Distribution – Mechanized Tunnelling
(Example of metro tunnel in soft ground)

RELIABILITY

The Seattle Sound Transit Project described the proposed mass transit project for the Seattle area. A major rail tunnel was proposed as a design-build project to expedite project activity. Sound Transit, the procurement authority, recognized the significant time savings that could be achieved by obtaining long lead items, such as a TBM and other materials as the design progressed. It was anticipated that early procurement, particularly the TBM, would save 15 months on the construction period. Experiences have been made with the advantages of design-build, particularly the ability to adopt innovative practices, allocate risk, and foster a partnering relationship among project participants. Design-build offered the freedom to be cost effective, control to get the desired end product and assurance that the project would be appropriate staffed.

Only two bids were received for the Seattle project, each bid was approximately $800 million, far exceeding the $500 million anticipated budget. Sound Transit examined cost reductions with one bidder, but could only reduce the projected cost to $700 million. Further study of the original estimate suggested that the proper estimate should have been $807 million. The cautions to be observed based on the Seattle experience:

- Scope must be clearly defined, in order that inclusions and exclusions are clearly identified
- Changes must be managed
- Cost estimates must be realistic
- Issues must not be over-simplified

The suggestion to include a time frame that distinguishes early project activities was discussed. The initial portion of the project, a 14-mile Segment of Seattle Light Rail is proceeding under traditional procurement methods.

RISK ANALYSIS VS. COST OVERRUN

It is necessary to address the risk factors which will give best value. The three most important risk factors are:

- The **"Retained Risk"** which, by its nature, always rest by the public sector. An example is the London Underground PPP where the risk of fare revenue falling below its expected level.
- The **"Base Cost"** of providing services required by the public sector. For LU this is principally the public's sector estimate of what it will spend to enhance, maintain and manage the infrastructure over 30 years in accordance with the performance. The "Base Cost " projections have been prepared in four categories : major investment costs, steady-state investment costs, maintenance costs and other infrastructure company costs as e.g. management and overhead costs of the new businesses.
- The **"Risk Adjustment"** of the base cost figures, to reflect the probability that service will not be delivered at the cost shown in the base cost projection because of events like cost overruns or technical problems, or that the budgets may be maintained but at the expense of reductions in service quality.

Special attention has been paid on procedures of risk analysis regarding financial aspects of the project. Following the procedures for risk analysis identification and categorisation of risks have been stated: risk register has been prepared to identify and categorise the main project risks according to their allocation.

- **Design and construction risks** (principally failure to deliver enhanced assets as required by the performance specification due to : poor or inadequate design, design errors, late changes to design or the late delivery of completed design, implementation risks such as site access problems, unforeseen ground conditions, weather, or archaeological discoveries, interferences from other parties, cost overruns)

- o **Demand and revenue risks** (as e.g. availability of services and related assets, failure to meet required "scheduled-journey-time-capability", poor ambience of trains and stations)
- o **Operating and maintenance risks** (as e.g.: cost of operations, availability of staff, spares and consumables, fire, theft accidental damage and vandalism to the extent that these cannot be covered by insurance)
- o **Other risks** (such as: availability and cost of finance, changes in law, taxation, general inflation etc.).

Quantification of risk needs to be cross-checked from independent interdisciplinary experienced estimators, financial experts have to question the management to test whether the financial risk quantification can be regarded as financially sound for this purpose. Where risks could be mitigated by insurance (for example the risk of fire) the insurance premium which could be obtained form the market needs to be considered.

The risk analysis has taken measures to avoid double counting of risks and took into account any correlation between them. For example:

- o If the quantification of potential cost overruns partly reflects the possibility of increased staff costs then there should be no separate allowances for differential wage increases over and above inflation.
- o It will be estimated that there is a correlation between unforeseen ground condition costs and the risk of contractual claims etc.

The allocation of risks between the parties is fundamental to making sure that only bankable projects are brought to the market. Prior to introduction to the market the project has to be subjected to rigorous risk assessments within own risk profile. One risk management methodology needs to be established consisting of following:

- o Establish objectives and risk appetite
- o Risk identification, classification and allocation
- o Assessment, impact and quantification
- o Identify mitigation procedures
- o Prepare or update risk register

The purpose of this approach is to ensure that no risks are overlooked, and that all identified risks are monitored and managed in order to minimize potential adverse impacts. Identification of risk will be continuous activity throughout the development of a project. A starting point is to establish the broad categories within which risks will be analysed and to define their allocations as shown in Tab.1.

Risk category	Procurement Agency	Private Partners	Shared Risks
Land acquisition	*		
Railway order			*
Utilities			*
Design, Construction, Supply		*	
Commissioning, Operating, Mainten.		*	
Demand			*
Residual value		*	
Technology and obsolence		*	
Regulatory, Legislative		*	
Environment		*	
Financial		*	
Safety		*	

Tab. 1 Risk Allocation Matrix

While the risk allocation outlined in table 1 is recommended, it is sure that the finding of final risk allocations is an iterative process through which initial positions will change as a result of actual experience and interaction with the partners throughout the tendering and/or negotiating processes on specific projects. The structuring of infrastructure transactions will be heavily influenced by models which have been adopted for large scale project financing transactions. The primary commercial and financial objectives will relate to:

- o clear responsibility for the ownership and management of risks
- o no preference on funding structure, the exact nature of funding will depend on specific project risks
- o to transfer revenue risk where it is appropriate and provides value for money

- payment mechanism and performance should complement each other
- preferred position on risk allocation as shown in Tab. 1

BALANCING OF COST

In order to balance cost in underground design and construction critical contracting issues have to be identified. In this context various construction methods and contract models need to be examined and potential approaches have to be proposed. It is especially necessary to identify issues of risk sharing, quality, design and construction cost and schedule.

Construction Issues

Issues of construction are related to subsurface and geotechnical issues, utilities and buried structures, third party approvals and permits, differing site conditions, contractors contingencies and risk sharing and risk management.

Geotechnical Risks

Balancing of cost will specifically be influenced by geotechnical risks related to difficult ground conditions, contaminated soil and ground water, boulders and buried objects, extent of geotechnical investigation, as well as interpretation of geotechnical data and ground behaviour.

Geotechnical Disclosure

Geotechnical issues are of paramount importance in regard to cost balancing. There are numerous standard reports which should be fully disclosed to the parties interested in the project. Such reports are Geotechnical Data Report, Geotechnical Baseline Report, Geotechnical Summary Report and Geotechnical Interpretive Report.

Risk Management / Sharing

It has shown that underground infrastructure design and construction needs not only risk management but also fair risk sharing. Therefore it has proven in many countries that a dispute review board is giving benefit to all parties involved in the project. Escrow bid documents did show to be useful as well. In the project differing site conditions should be addressed in a different site condition clause. Value Engineering should be useful in order to allow the contractor to offer his experiences and new technologies to the client on the basis of acceptable partnering conditions.

An owner controlled insurance program will be helpful in this context. Unit prices in a fair combination of lump sum costs will help to avoid disputes. Contingence bid items are generally used as part of the contract as well as owner directed works. It has shown to be beneficial if incentives for early completion of the project, achieved high safety standards and good quality have been included in the contract.

CONTRACT MODEL INFLUENCE ON COST

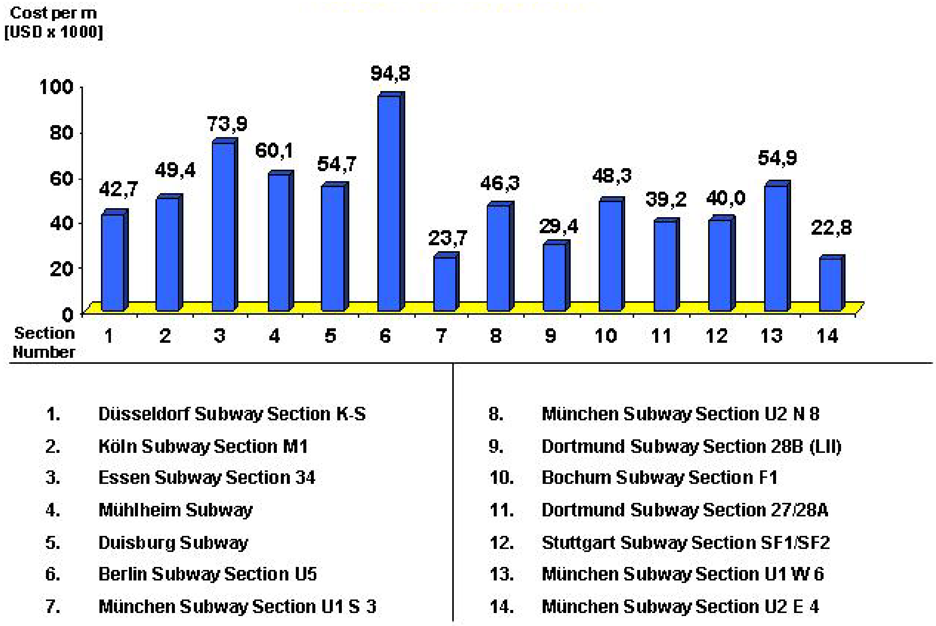

Fig. 3 Cost overview contractor design / build contract type

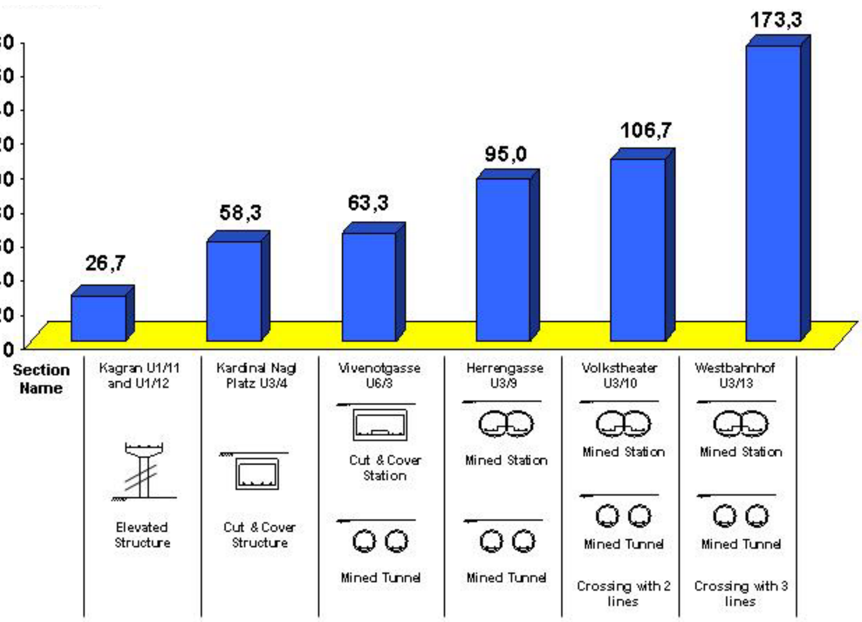

Fig. 4 Cost overview client design bid / build contract type

A cost overview is shown in fig. 3 and fig. 4 comparing two different contract types. This cost comparison includes different construction methods, in particular elevated structures, cut & cover structures, mined tunnels with cut & cover stations, mined tunnels with mined stations, mined tunnels with crossing of two lines and mined station and mined stations with crossing of three lines. It is assumed, that all this different technologies of construction may occur in a very approximate comparison in different European Cities knowing that the result has more a qualitative than a quantitative character. However it shows that there is a significant cots advantage when using the design / build contract type for inner-urban structures with the contractors experience in the frame of competitive bidding. In the case of the above examples this cost governance of the design / build contract may in the range of up to 45 % of cost savings to the client.

CLOSING SUMMARY

The cost governing experience with design / build tunneling projects is encouraging for the future. It has been observed that European functional tendering has been useful. It remains intended for use on future high-speed railway projects, e.g. in southern Germany. The critical examination of geotechnical risks well in advance of project activity has been advocated. It has been further asserted that the European practice of requiring the contractor to perform his own exploratory work during the bid may result in poor quality or disparities in information, leading to high claims during construction. It has to be concluded that there have been positive experiences and lessons learned in design and construction of tunneling that will chart the course for better cost governing experiences in the future.

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