Dieter Jacob/Clemens Müller

Estimating in Heavy Construction

Roads, Bridges, Tunnels, Foundations

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Foreword

There is no up-to-date English language textbook on heavy construction calculation/estimation, in contrast to building construction. This may be because this type of construction often involves heavy construction machinery from Germany and Asian countries. Therefore, I appreciate that such a textbook for contractors as well as clients has been provided.

This book can be used for US heavy construction, as well as heavy construction in Asia and developing countries. The examples are calculated in euros and can easily be changed into USD. The examples have to be adapted to the local/regional conditions with regard to wages and material costs. The sales tax/value added tax as used also needs to be adapted.

The book provides a good basis for estimation because all important cost categories are considered. The risks of different construction contracts are systematically evaluated with regard to risk distribution between owner and contractor. Specific risks, for instance for joint ventures, are also considered. A systematic scheme for the calculation of interim interest is provided as well.

The book differentiates between time-dependent and time-independent costs. This allows one to easily calculate the costs caused by delays. The initial strategy part of the book considers the effect of different levels of capacity utilization and the cost/profit consequences. The calculation/estimation is not presented as a deterministic process, but the book shows how this depends on strategic considerations, subjective factors and stochastic characteristics. The book also demonstrates the application of cost estimating software.

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Preface

In contrast to building construction, there are only a few available English books on estimating in heavy construction projects, such as roads, bridges and specialized foundation engineering works for buildings. This book is based on our German estimating book, in which we have collected German examples. These real projects can also be applied to the international market.

The estimating is based on specific construction methods which are dependent on the boundary conditions, the machinery available and the quality and training of personnel.

Be aware that estimating is always a stochastic process and cannot deliver a deterministic result. Reliable estimating is not only important for a contractor but also for a professional client who wants to have a rough overview of his cost situation, especially in civil engineering and underground construction. This is expensive, complicated work and one cannot simply measure square or cubic meters of living space as in standardized building engineering. One only has to think of related significant cost overruns in a few recent large-scale projects to understand the need for a publication written exclusively for heavy construction estimating.

We would especially like to thank all contributing heavy contractors such as Strabag Großprojekte GmbH, VINCI, Heijmans Oevermann GmbH, BAUER AG and Matthäi Bauunternehmen GmbH & Co. KG for their support.

Freiberg, September 2016 Dieter Jacob, Clemens Müller (Editors)

Table of contents

2 Estimating costs in heavy construction

2.1 Foundations of construction business management

2.1.1 Estimating goals

The cost estimate is structured according to Figure 2.1:

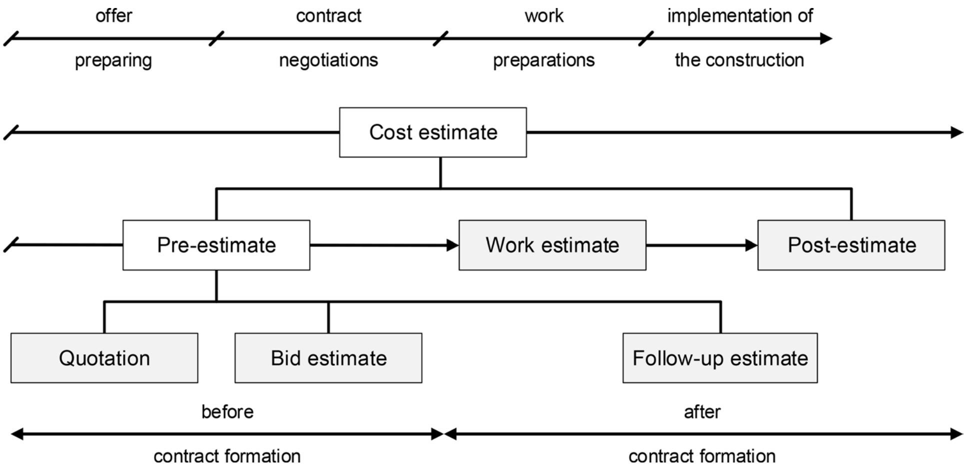

Figure 2.1 Cost estimate structure before and after order placement[1)]

The goal of forecasting is to determine the production cost basis of a construction project with respect to the processing costs, including all capital costs.[2)] This is used as the baseline for negotiating prices with the potential customer.

In our financial system the price is determined by the market and therefore is not directly related to the production cost basis for a product. Management thus requires further accounting information for the negotiation of prices, for instance the lowest price limit or liquidity costs. In addition, due to "target costing", this preliminary, projected calculation adds to the importance of the retrograde calculation.

When planning target costs, one starts with the market price and subtracts what individual project components may cost according to the predominant market price.

Time-variable costs also remain important. The time-dependent costs are decisive and result from the construction plan, which takes the form of a time-performance diagram.

A further goal of forecasting could be to obtain information about the prospective liquidity development of a project before signing the contract. This may be done in order to recognize the need for liquidity - or excess liquidity - and to determine financing costs.

1) In accordance with Drees/Paul (2015), p. 20.

2) Cf. Hauptverband der Deutschen Bauindustrie e. V./Zentralverband des Deutschen Baugewerbes e. V. (Ed.) (2001), p. 30.

2.1.2 Key financial cost terminology

2.1.2.1 Delimitation of costs and expenses

It is necessary for the terms "total expenses of the financial accounting" and "total costs of the management accounting" to be clearly separated (cf. Figure 2.2).[3)]

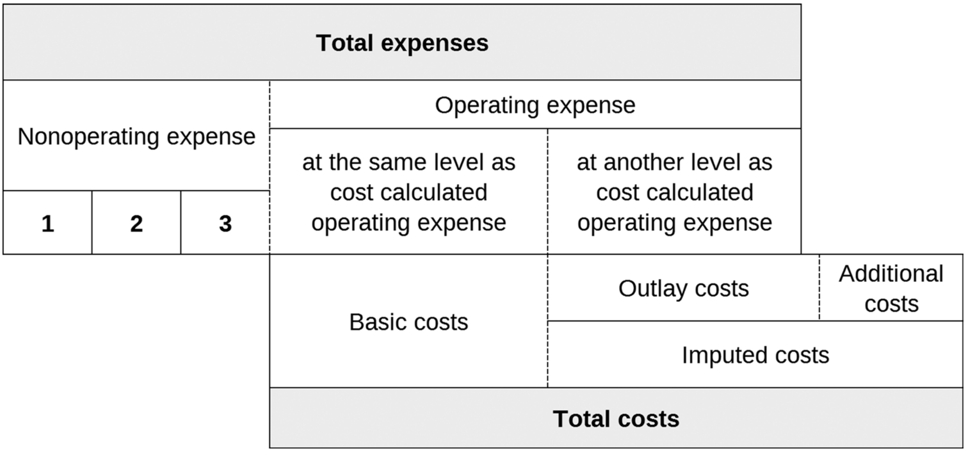

Figure 2.2 Demarcation of the terms expenses and costs[4)]

The total expenses consist of non-operating expenses and operating expenses. The non-operating expenses relate to (1) other periods (2) external expenses or (3) extraordinary expenses. The expenses relating to other periods correspond to the expense of previous business years, for example, additional tax payments. External expenses arise through the pursuit of non-operational goals (e. g. charity). Expenses that are usually not expected in the context of ordinary operational procedures (e. g. fire damage) belong to extraordinary expenses.

The part of the operating expense that is calculated as being equal to the costs represents the basic costs in the management accounting. Examples of this include, but are not limited to, the consumption of construction materials, wages, salaries, or subcontractor expenses.

The part of the operating expense that is calculated as being different to the costs constitutes the outlay costs (i. e. imputed instead of balance sheet depreciation) in internal accounting. The costs not faced with coinciding expenses are referred to as additional costs (i. e. imputed management wages, interest payments on equity, etc.). Outlay and additional costs constitute the imputed costs. Together with the basic costs, these constitute the total costs.

3) The following parts are excerpts from Jacob / Winter / Stuhr (2008), p. 1112.

4) In accordance with Eisele (2011).

Finally, the operating expense and the running costs only differ with regard to outlay and additional costs. This is very important for management, because the period costs used by management must be, to the greatest possible extent, equal the operating expense of the financial accounting (cross-check by offsetting and reconciliation).

2.1.2.2 Direct costs and indirect costs

In the estimating process it is exceptionally important to differentiate costs according to their imputability.[5)] Therefore, direct costs and indirect costs can be differentiated. All costs that can be directly attributed to specific cost units (e. g. building part), belong to the direct costs. Direct costs are used in cost type accounting and are assigned to a cost object. A cost allocation across multiple cost objects cannot occur. The types of costs that can only indirectly be attributed to a cost object by way of redistribution or remuneration are considered non-costs. The artificial indirect costs constitute a unique situation. These can theoretically be directly accounted to a cost object, but are nevertheless treated as indirect costs for financial reasons.[6)] Examples could be additional materials or certain small materials (i. e. screws).

2.1.2.3 Time variable –time fixed costs

Proper costing of a planned construction project necessitates the differentiation of the prospective costs according to their chronological order.[7)] While some types of costs change according to the duration of the construction project, others are set only once and are hence independent of the construction time. Thus, classifications of both time-variable and time-fixed costs can be made.

Time-variable costs of a construction site include:[8)]

– Contingency costs[9)] (equipment, special plants and machines, accommodation, trailer, contractor’s shed, vehicles, fixtures, office equipment, scaffolding, framework and pit lining supplies, external and safety scaffolding, security facilities, and traffic control installations)
– Operational expenses (equipment, special plants and machines, accommodation, trailer, vehicles)
– The expense of the site management (supervision and coordination)[10)] (salaries, telephone, postage, office supplies, automobile and travel costs, hospitality and advertisements)
– The general construction costs (auxiliary e. g. for security staff, surveying assistants, supply costs for the construction site, maintenance costs of paths, squares, roads and

5) The following remarks are extracted from Jacob / Winter / Stuhr (2008), p. 1102 f.

6) Cf. Götze (2010), p. 20.

7) The following remarks are extracted from Jacob / Winter / Stuhr (2008), p. 1103 f.

8) In accordance with Drees / Paul (2015), p. 90.

9) In the case of a longer construction time the construction project has to be charged with a higher proportion of contingency costs for the operating supplies used.

10) In the event of an extension of the construction time, the construction project will be burdened with a higher proportion of labor costs.

fences, lease and rent e. g. for accommodations, offices, construction site facility locations, time variable costs)

Time-fixed costs of a construction site include:[11)]

- Time-fixed costs of the construction site facilities (loading costs, freight costs, assembly and disassembly cost for equipment, accommodation, site trailers, trailers, telecommunications, water supply / sewage disposal, access, paths, fences, work bays and storage place, all kinds of scaffolding, security facilities and traffic control installations)
- Costs of the construction site equipment (auxiliary material; small agricultural equipment and tools, office equipment, accommodation, sanitation facilities, so far as they are not already included under contingency costs)
- Engineering processing and technical control (structural editing, work preparation, construction material tests, soil analysis)
- Construction risks (unique risks arising from the construction process which are confined to the construction project, e. g. adverse weather, high and low water, limited construction times leading to time limit violations and subsequent contractual penalties, the implementation of new construction methods; insurance covering all unique risks arising from the construction process throughout the project's operations)
- Additional charges (abnormal construction interest; license fees, working group costs for both technical and business management, additional provisions for winter construction, and other individual costs)
- Disposal of construction waste and / or construction material (excavated earth, construction rubble, construction debris, road surface material, special waste e. g. colorants and packages of paints, mineral oil etc.)

A differentiation of the costs according to their chronological behavior is also necessary when estimating special cases, namely cases regarding changes in the cost range after the contract terminates and disruptions of the construction schedule (cf. section 3.1). In conjunction with estimating special cases, which may cause a reduction in the contractually established scope of performance, the extent to which costs are remanant should also be examined. Cost remanence indicates that the costs decrease more slowly as a result of a decrease in activity than they rise as a result of an increase in activity. It follows that there are certain costs that are not extractable in the short-term. An example of this is the use of special construction materials that the contractor has already purchased, which, as a result of the reduction in the scope of performance, are no longer needed to their full extent and are also unlikely to be utilized by construction projects in the foreseeable future.

2.1.2.4 Company related – project related costs

Company related costs, i. e. those costs that originate from all operations of the company, which are attributed to the establishment's location and the central headquarters include:[12)]

11) In accordance with Drees / Paul (2015), p. 90.

12) Jacob / Winter / Stuhr (2008), p. 1104.

- Short-term non-degradable costs that guarantee the readiness of production, e. g. wages and salaries of the senior staff (including legislation and agreed social costs), rental costs, depreciation and interest costs of constructions and equipment
- Cost of lighting, heating, cleaning, office equipment, phone, marketing, legal expenses, and consulting fees etc.
- Cost of the construction yard, repair workshop, vehicle fleet
- Taxation or public charges
- Contributions to organisations
- Insurance, as far as it does not concern individual construction projects,
- Transaction costs (costs of initiation, agreement, settlement, alignment, and auditing of contractual relations), including the costs of unsuccessful acquisition attempts
- Cost of enterprise-related risk
- Costs of warranties and sureties (basic fee)
- Imputed entrepreneurs' salary

Project-related costs are especially contributed to:[13)]

- Cost of construction materials, auxiliary construction materials, and operating supplies
- Cost of third-party work and subcontractors
- Costs of loading, freight, assembly, modification, and dismantling of the company equipment
- Transportation costs of construction site supplies
- Cost of energy, water, waste water, and telecommunications
- Costs of the construction, maintenance and repair of entry-ways, paths, barricades (e. g. fences), storage facilities, cost of traffic security
- Miscellaneous costs from leasing and renting
- Cost of construction waste and / or construction material disposal
- Costs arising from project-specific risks
- Cost of project-specific insurance
- Cost of guarantees and sureties, in so far as they are performance dependent,
- Cost of weather-related compensation
- Cost of legal project auditing
- Cost of interim financing for the construction project related loan costs,
- Other costs (e. g. local advertising costs, travel costs, special joint venture costs)

Project-related overhead costs, which can only partially be imputed to the project, include imputable time-dependent depreciation for the operating supplies and the costs of preventive maintenance.

2.1.2.5 Liquidity-related and non-liquidity-related costs

The differentiation between liquidity-related and non-liquidity-related costs plays a very important role in price policy considerations.[14)] Essentially, the offer price should cover the liquidity-related costs. When computing the lowest price limit for maintaining liquid-

13) Jacob / Winter / Stuhr (2008), p. 1104.

14) The following remarks are extracted from Jacob / Winter / Stuhr (2008), p. 1105 ff.

ity, costs that become cash-effective only in the long-term are not covered in the computation.[15)] This includes interest on equity and the depreciation of equipment, machines and property. For the calculation, other essential purchases must also be considered. The lowest price limit for liquidity maintenance, therefore, is determined as follows:

	Net offer sum
–	Risk and profit
–	Interest on the equity capital
–	Depreciation of constructions, equipment, and equipment
=	Lowest price limit
+	Essential purchases
=	Lowest price limit for liquidity maintenance

2.1.2.6 Capital cost

The concept of capital cost stands in the context of the requirement of return on investment (RoI).[16)] For the use of dept capital, a requirement for a minimum return on investment is defined according to the rights and duties of the related financing and by the risks of investment. The cost of capital includes the borrowing cost of capital, equity financing cost, and the transaction costs associated with the purchase, management, and repayment of the capital.

The borrowing cost of debt financing are costs that result directly from the borrower's credit relationship, including the acquisition fee and disagio, and possibly a risk premium (credit spread).[17)] Equity financing costs differ by business entity type, which range from individually owned companies, such as sole proprietorships or business partnerships, and corporation-based companies, such as limited partnerships or corporations. In the former case, the costs are defined according to the investment alternatives of the shareholders, because they expect a rate of return on their capital investments that is at least as high as the most favorable omitted alternative.[18)] Should the individual investment alternatives have different levels of risk, a risk premium should be calculated. For corporation-based companies, the equity costs are derived from the sum of shareholder claims with respect to dividends and the value appreciation of shares. Here, alternative investment forms also play a role. The (total) capital costs are determined by the sum of the weighed costs of debt and equity financing.

The weighted average cost of capital with respect to the capital market is usually determined using the capital asset pricing model (CAPM).[19)] Because a large number of construction companies are unlisted, the necessary beta factor for the cost-of-equity

15) Cf. a construction related depiction: Speer (1997), p. 157.

16) Cf. the comments below on Drukarczyk (1998), pp. 404–407 and Süchting (1998), p. 745.

17) Cf. the comments below on Perridon/Steiner/Rathgeber (2009), p. 495.

18) Ibidem, p. 495.

19) Cf. for instance, Gladen (2014), pp. 119–126.

rate cannot be determined. The determination of capital costs in the construction industry can be illustrated as is presented in section 2.1.7.3.

2.1.3 Types of construction contracts

In practice there are a number of different types of contract. The most commonly used construction contracts are:

- Unit-price contracts
- Lump-sum contracts (global and detailed lump-sum contracts)
- General contractor contracts
- Output-oriented construction contracts (also referred to as Funktionsbauvertrag)
- Turnkey construction contracts
- Guaranteed maximum price (GMP)
- Operator contracts
- Renovation contracts
- Contracts for the entire life cycle of a construction project, such as build, operate, transfer (BOT) contracts and public private partnership (PPP) contracts

The technical specifications of a construction contract may be input or output oriented. The unit-price contract is typically input oriented, whereas the functional construction contract is typically output oriented.

All types of contracts can either cover the entire life cycle or phases thereof, meaning the planning, construction, and/or operation phases. In each individual phase there may be subsections, such as planning permission or construction services planning, or a planning of the entire phase, as is in the example here of general planning. The same applies to the construction phase. This may also be applicable for a single project subsection or for an entire construction project, in which case a general contractor contract would be used. The interfaces within a life cycle phase or between life cycle phases have to be covered by additional specialists, such as project managers.

Among the different types of construction contracts, there are varying distributions of risk between client and contractor. In particular, with output based specifications, it is also possible for a contractor to introduce certain innovations in several ways.

Due to the importance of both unit-price and lump-sum contracts in practice, these two types of contracts are now explained in more detail.

The *unit-price contract* includes a bill of quantities and a description of the partial services or items to be executed, which is part of the contract's underlying specifications. The bill of quantity contains the expected quantity, the unit price determined by the contractor and the total price (derived by multiplying the quantity by the unit price). Individual items can be listed as flat rate and compensated accordingly (e. g. construction site facilities). In the unit price contract, the total compensation is determined only after the completion of the work. This is because specified antecedents in the specification are variable and can serve only as guidelines. The billing of the services rendered is measured according to the actual quantity. If the parties agree that special

Summary

Construction site facilities	192,216.71 EUR
Bridge structure	132,038.15 EUR
Bridge construction total	324,254.86 EUR
Bid sum (net)	324,254.86 EUR
VAT (19 %)	61,608.42 EUR
Bid sum (gross)	**385,863.28 EUR**

2.5 Estimating in tunnel construction

2.5.1 Introduction

In a first basic categorization, tunnel construction may be divided into open and closed construction methods. Open construction means the tunnel construction site is created in an open construction pit, which is refilled after project realization. This method is usually employed for tunnel structures close to the surface. In the latter case, the tunnel is excavated either using a tunnel boring machine (e. g. cutting shield or open tunnel boring machine) or using mining techniques (conventional excavation using means of, e. g., boring or explosives).[58] A special case in tunnel construction is the so-called floating assembly method for submerged construction, in which one or more caissons are submerged and then connected to one another so as to keep the whole construction watertight.[59]

2.5.2 Example – Cutting shield boring

2.5.2.1 Work specifications

The following chapter addresses estimating processes and involved costs for boring two tunnel tubes (east and west tube) of a tunnel structure, running in north-south direction, as underpass to a river. Planning involves employment of two tunnel boring machines (TBMs) for this construction. In this example, both tunnels are created in a depth of 60 m below ground level with cutting shield and will have a final length of 6.6 km. The excavation chamber is supported with bentonite.

Using the cutting shield construction method, a steel cylinder, the internal diameter of which is slightly larger than the outer diameter of the tunnel wall, is pushed into the soil with hydraulic presses. Covered by the cutting shield, the forward part of the equipment excavates the soil while the final ring-shaped tunnel is created in the wake of the machine. The annular clearance between outer tunnel wall and surrounding mountainous soil emerging during the boring process is grouted (i. e. sealed) immediately.

Prefabricated tunnel segments made of reinforced concrete are used for this process in this specific example. Hydraulic presses employed during the boring process are

58) Cf. closed construction method with tunnel boring machines, e. g. in Girmscheid (2008), pp. 381–436, and cf. boring methods using conventional means or explosives in ibidem (2008), pp. 71–132.

59) Cf. floating assembly method and caissons respectively in Lingenfelser (2001), p. 233 ff.

supported with thrust pads in the finalized parts of the tunnel. The cutting shield is controlled through pressure redistribution, which allows it to bend the tunnel. The minimum radius of the cutting shield is given with 50 m, whereas the shield's outer diameter defines the boring process and excavated volumes. Boring with a cutting shield is mostly used for excavating in loose rock and cohesive soils.

In this case, the excavated rock face is supported by slurry under pressure, which completely fills the tunnel, sealed off tightly against the boring area, up to the roof and exerts pressure onto the rock face. Either cutting equipment or star-shaped cutting wheels are used for excavation. During the boring process, slurry is mixed with extracted soil. The mixture is transported above ground and separated with the slurry being pumped back into the excavation area. Here, pressure of the supporting slurry needs to equal earth pressure and stay constant. Pressure equalization may be attained through controlling the flow of slurry from and to the excavation area or through assembly of an air compression chamber where controlled air pressure is exerted at level of the supporting slurry. The basic structure of a TBM is shown in Figure 2.13.

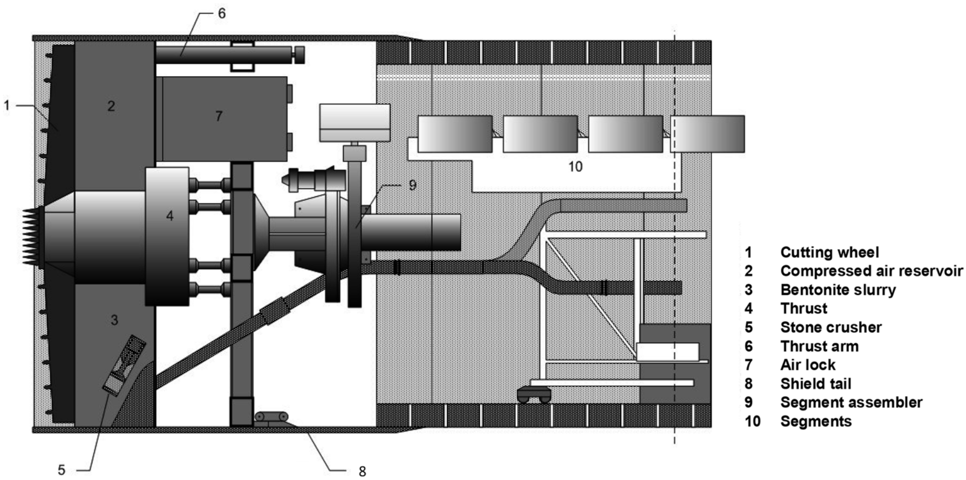

Figure 2.13 Schematic section of a tunnel boring machine

In case of emerging obstacles or cutting wheel maintenance requirements, the supporting slurry is displaced with compressed air. Operations in the excavation area may then proceed under compressed air. Staff is transported to and from the excavation area via airlock. In ground water areas, the tail end of the cutting shield has to be made watertight to prevent the intrusion of ground water.

Contractual conditions
Contractual agreements in tunnel construction for the provision of TBM by the manufacturer usually include a number of items with respect to performance and process times as well as TBM availability, which guarantee a certain boring rate. This boring rate is part of the most substantial bases for the calculation of prices and costs by the contractor for creating both tunnel tubes.

In general, guarantees involve times and rates of processes crucial to the boring of the tunnel tube:

– Boring with cutting wheel
– Assembly time of prefabricated tunnel segments
– Extending supply and disposal pipes
– Availability of the TBM for boring processes
– Average boring performance

2.5.2.2 Boring rate and progress rate

Boring rate
Boring rate defines the actual boring process, i.e. the process during which the TBM actually progresses through rock and soil. With respect to geological conditions, the TBM manufacturer guarantees varying boring speeds. Table 2.28 shows guaranteed average boring speeds in mm/min relative to geological conditions and layers as well as hydraulic pressures present in the geological sections that have to be bored through. Additionally, the table includes boring rates in m/h and m/WD.

Table 2.28 Development of boring rate in tunnel construction

Pos.	Geological layers	Type of operation	Boring location Start [m]	Boring location End [m]	Boring length [m]	Contractual cutting speed per geological layer [mm/min]	A [m/h]	Boring performance: Operation time T_T [h/WD]	Boring performance: Boring performance B [m/WD1)]
1	Sand (Z1)	Test Drive	0	230	230	40	2.4		
2.1	Sand/Clay (Z1/BK1)	Test Drive	230	300	70	30	1.8		
2.2	Sand/Clay (Z1/BK1)	Regular operation	300	350	50	30	1.8	24	43.2
3	Sand/Clay (Z1/BK1)		350	420	70	30	1.8	24	43.2
4	Clay (BK1/2)		420	570	150	20	1.2	24	28.8
5	Clay/Sand (BK2/GZ2)		570	850	280	30	1.8	24	43.2
6	Sand (GZ2)		850	1,430	580	35	2.1	24	50.4
7	Clay/Sand (BK2/GZ2)		1,430	1,980	550	30	1.8	24	43.2
8	Clay (BK1/2)		1,980	3,980	2,000	25	1.5	24	36.0
9	Sand/Clay (GZ1/BK1)		3,980	5,180	1,200	30	1.8	24	43.2
10	Sand (GZ1/Z1)		5,180	6,260	1,080	40	2.4	24	57.6
11	Sand (GZ1/Z1)		6,260	6,600	340	40	2.4	24	57.6
					6,600	31.2	1.9		44.9

1) WD = Workday = 24 h

A x 24 h/WD = **B**

Ring construction

In order to expedite the boring process as much as possible, it is important to keep the period needed to completely assemble a ring of eight prefabricated reinforced-concrete tunnel segments (7 + 1 ring construction time) and reattach hydraulic presses as short a time as possible, which is pivotal to the cumulative boring rate.

Provided that qualified staff is on site, the TBM manufacturer guarantees that construction time per ring does not exceed 30 minutes.

The same applies for the extension of supply pipes. However, since extensions may be realized parallel to ring construction, some of the time needed for the effort is “dwarfed” by the ring construction time. As a result, the greater amount of time spent with respect to the cumulative boring rate is reflected in the calculation process.

Moreover, the TBM manufacturer guarantees that pipes for „slurry cycle, water supply, emergency drainage and emergency air supply“ can be extended over a length of 12 m within 45 min.

The calculation process for the required boring rate or, conversely, the required amount of time it takes to bore a certain distance, consists of the partial processes above. The process also involves further amounts of added-on or lost time resulting in an average rate, which stays consistent over longer periods of time. This state of consistency usually only arises after the TBM and its tail are inside the tunnel tube over the full length of the machine, and an initial, so-called “test drive” has been completed.

The TBM manufacturer guarantees that after completion of the initial test drive over the first 300 m, an average boring rate of 15 m in 24 h over a total period of six days will have been achieved. The manufacturer has to provide proof of this average in an agreed section between 300 and 600 m.

2.5.2.3 Availability

In order to plan construction of a tunnel according to schedule and within the deadline, the average continuous rate is important. Making an estimate regarding the average continuous rate in conjunction with the above mentioned performance restraints is only possible under provision of an unimpeded operation of the TBM.

“Availability” in this case is determined as the ratio of time within three shifts of eight hours per workday (WD), during which operations are supposed to run with the boring personnel, and the time during which the TBM is actually available for boring, ring construction, and pipe extension operations in an unimpeded manner.

For every TBM, the manufacturer guarantees that after 300 m of test driving, there will be an operative availability of at least 85 % of the construction time for boring and assembly of tunnel ring segments, respectively. Construction time means the period of time during which the staff of the contractor is available for construction purposes (a three shift system from Monday morning at 6:00 a.m. to Sunday morning at 6:00 a.m. is assumed). This potential working time might be reduced by:

– Downtime caused by the tunnel contractor
– Delays due to damages done to equipment involved in the boring process, caused by tunnel contractor
– Planned maintenance
– Downtime caused by replacement of excavation or cutting devices

Calculation of availability is performed according to the following formula.

F availability

T_T actual working time

T_A downtimes due to TBM maintenance etc.

T_1 operational downtimes

T_2 damages

T_3 maintenance

T_4 device replacement

$$f\left[\%\right] = \frac{T_T - (T_1 + T_2 + T_3 + T_4) - T_A}{T_T - (T_1 + T_2 + T_3 + T_4)} \times 100$$

Availability is measured from the moment the first permanent ring has been assembled to the moment the TBM arrives at level of the created wall of the reception shaft. Availability is calculated on a monthly basis. Procedures for registration, definition, evaluation and reporting are included in the non-optional manual provided by the manufacturer upon receiving the TBM. The test drive is included in the calculation of availability. Monthly recalculations are sensible in this regard, rather than on the basis of the whole construction period of two years and three months, as possible later adjustments of the TBM by the manufacturer have to be considered in the sense that "catching up later" is prone to quickly reach technical limitations.

The boring progress and tunnel construction directly influence costs regarding time and performance required during the tunneling project. It is hence imperative to differentiate and compare guaranteed, calculated, and actually achieved progress speeds.

2.5.2.4 Classification of work-shift times of boring personnel

Eight-hour-shift times are usually classified in shift protocols and weekly reports as follows:

1. Boring time
2. Ring construction time
3. Downtime
4. Time working under compressed-air conditions
   (1) Boring time is the part of the construction schedule, during which the TBM is driven forward along the conceived tunnel path via hydraulic presses.

(2) During ring construction time, the TBM is at rest, which is inherent to the tunnel construction process as hydraulic presses are retracted in this stage. While the TBM is down, a ring consisting of 7 + 1 prefabricated reinforced-concrete tunnel segments is assembled. Furthermore, the extension of supply pipes after 12.0 m of boring progress falls into this category. The resulting normalized cycle is shown in the following figure, which depicts six rings for every 12 m of boring progress and a target cycle time of 9.55 h and target boring rate of 1.26 m/h.

(3) Downtime denotes any irregular suspension of operations and, in part, contingent downtimes, which commonly emerge during boring processes with cutting shield. They occur randomly with incalculable suspension times. Later chapters show a categorization of downtimes according to their sources.

(4) Working under compressed-air conditions means periods of time, also viewed as downtimes, during which maintenance work is performed in close proximity behind the cutting wheel requiring intervention with compressed air inside the compression chamber. Such periods may occur due to machine faults as well as geological or mechanical reasons.

Classification of boring periods

In order to draw a comparison among forward-progress speeds, the boring rate is calculated using a number of indicators for progress speeds and times of sub-processes. The performance rate is given as boring progress per workday [m/WD]. Construction, as part of the cumulative construction time available for actual tunnel construction and boring, is performed during six workdays per week in three shifts, i.e. tunnel construction and boring take place 24 h a day. Chart 2–14, "Structural diagram of boring processes", gives an overview of the various boring periods.

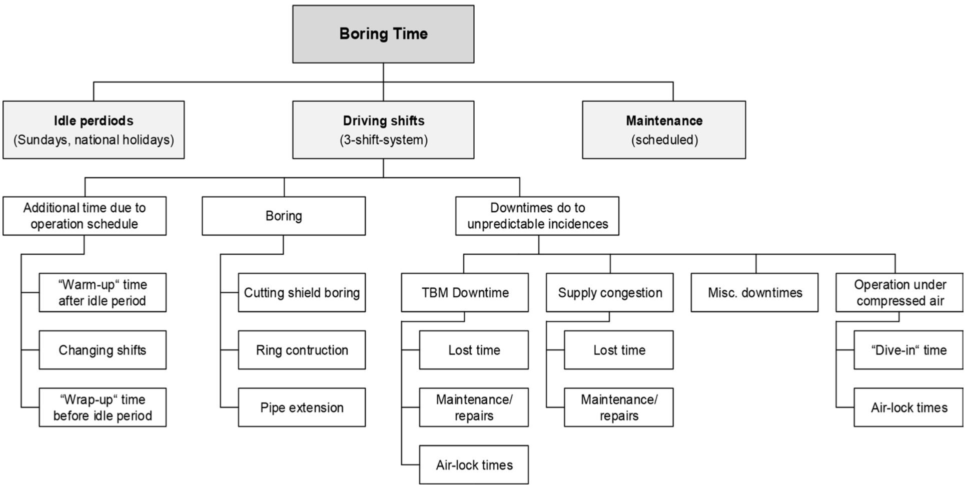

Figure 2.14 Structural diagram of boring processes

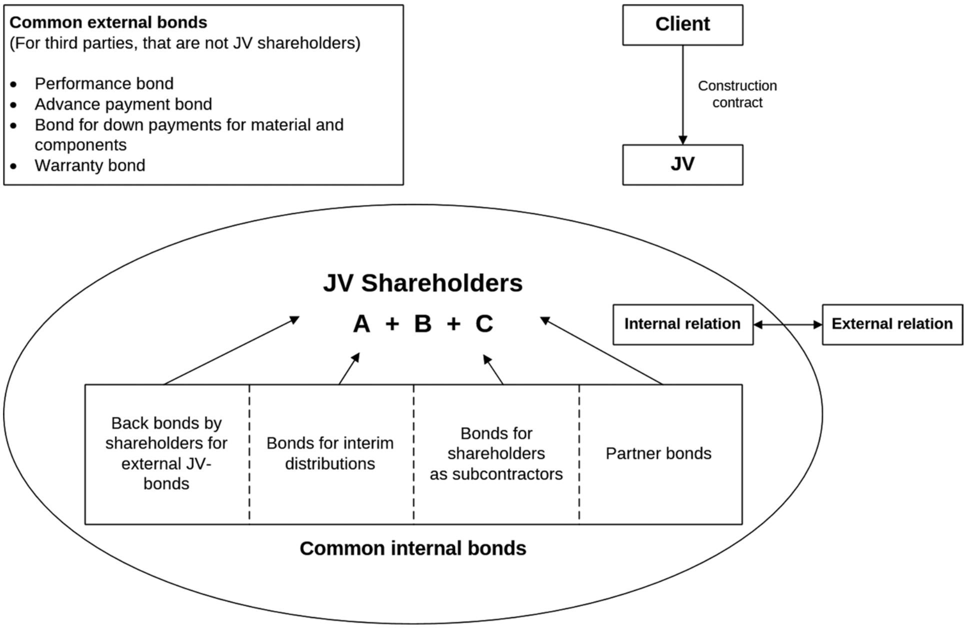

Figure 3.7 JV bonds[48)]

3.4.2.2 Joint liability

Each JV partner is jointly liable not only for their own activities but also for the activities of other JV members. This is particularly important if activities are realized poorly or if a JV partner declares insolvency. This kind of disturbance in delivery and performance can have an effect on the construction period as well as the later period of defect claims. However, it is possible to partially safeguard via provision of bonds or conclusion of specific insurances.

3.4.2.3 Insurance

Construction liability insurance
The object of construction liability insurance is to protect the contractor against financial loss, which may arise from the statutory liability associated with construction management. In order to obtain compensation for third-party damages through an insurance, a damage claim has to be filed. Hence, damages caused by the contractor are not covered by this kind of insurance. Liability insurance is a type of insurance that covers people, property or resulting financial loss. It is optional and is has no intention to pay, but to dispense from the claims of the damaged third party.[49)]

48) Cf. Burchardt (2009).

49) Cf. Wahner et al. (2008), p. 1205.

Construction companies, which are commonly involved in joint ventures, are covered by their completed-construction liability insurance, even without special agreements, when participating in JV projects. Each JV partner is insured in accordance with their share of the JV up to the agreed amount of coverage level stipulated in their construction-liability insurance contract.

If a shareholder ceases to be a member of the JV, the remaining shareholders are liable to fulfill the contractual activities. They have to provide the remaining activities of the former shareholder for the respective construction site and, if necessary, have to take on the additional insurance costs.

The JV may also take out construction liability insurance if the shareholders agree, and the adoption of costs is regulated. Thus even in cases where a shareholder ceases their JV operations, insurance cover is provided for the total performance.[50] This is particularly recommended for construction projects of a certain size within a JV.[51] In such cases, the most deciding factor is a cost comparison of individual insurance policies assuming costs for total coverage.

Construction performance insurance and other insurances
As the contractor is responsible for the accurate realization of their construction activities until acceptance of the finished construction by the client and since construction activities are exposed to various risks, some of them should be covered by construction performance insurance. Thus, any risks that may occur due to unforeseen damage to or destruction of the construction performance are protected against. However, construction performance insurance covers only property and does not cover staff, or financial loss. It includes construction activities (delivery and rendered services) of new constructions as well as renovations, and investments into related surrounding structures.

Insurance for additional interest for construction companies include, for example, environmental liability insurance, environmental damage insurance, and construction equipment insurance.

Additional acquisition and processing costs
Usually, each JV partner bears its own costs during the acquisition phase, which may lead to additional overhead costs owed to consultation of external professionals (e. g. lawyers, consultants, engineers, and cost experts). These additional costs have to also be defrayed in the event of an unsuccessful acquisition.

If the acquisition is successful, the JV is subject to additional leadership charges. Moreover, provided joint-venture billing rates are employed to calculate costs for staff and equipment, which may differ from the costs of own construction sites. All these considerations should be adequately reflected in the calculation.

50) Cf. Wallau / Stephan (1999), p. 99.

51) Cf. Wahner et al. (2008), p. 1203.

3.5 Using estimating software

3.5.1 Objectives and benefits

In heavy construction, the procurement process is subject to anumber of different constraints and conditions. Commonly, the time available for processing bids is particularly short. Nonetheless, quality requirements when determining bid prices are disproportionately high in order to generate an adequate construction result for acquired contracts. Moreover, 90 % of bids are not successful. They are, figuratively speaking, created to be discarded, which makes the situation all the more difficult.

With these issues in mind, the question of how EDP software can help support the process arises.

The structure and level of differentiation (of bids) need to be of significant quality for the calculation to effectively support the contract-acquisition process. It is the foundation for later work estimates, which, in turn, constitute the basis for an objective-oriented construction site monitoring. This sort of quality requirement is most efficiently realized through a customized master data calculation, which has been a tried and tested method with the following objectives:

- To assist contract acquisition
- To constitute a secure foundation to make bid decisions on business grounds
- To be a basis for the successful implementation of extra work and claims
- To constitute a foundation for result-oriented monitoring of construction sites (site monitoring)

This chapter, therefore, is intended to illustrate the objectives and benefits of EDP-supported bid calculation.

3.5.2 Recourse to master data

During the bid calculation process, client-side items listed in the specifications are used for the computation of economic bids. Functional bids that do not contain a bill of quantities have to be supplemented with the same by the contractor using provided bid documents. Expected costs for wages, materials, equipment, subcontracts, and other costs must be included in the calculation during the procurement process with values that reflect actual requirements as closely as possible. A regular, differentiated calculation lists individual activities separately. For example, formwork, reinforcement, and concreting.

Calculation data is basically differentiated into standard data and individual cost estimates. Calculation master data includes required information readily available and can be used for comparison (i. e. recourse) as follows:

1. Search and selection of a similar standard item; e. g. foundation concrete
2. Customization of specific cost estimates; e. g. material costs for concrete that are specific to the region

EDP support proceeds as follows:

- The task cost estimator selects the current item on the screen
- Using a selection template, the estimator searches in the standard project for a standard item closely similar to his own and inserts it via “drag and drop”.
- The selected standard item appears on the screen and allows the estimator to make the required, project-specific adjustments, e. g.:
  - Input of expected excavation rate in accordance with documented soil conditions
  - Input of region-specific material costs for concrete

The following screenshot shows the standard item “concrete foundation.” The EDP-supported master data calculation is performed as follows:

- Task: Calculation of a concrete foundation
- Search in standard project: Estimator finds similar item in standard project; see following figure:

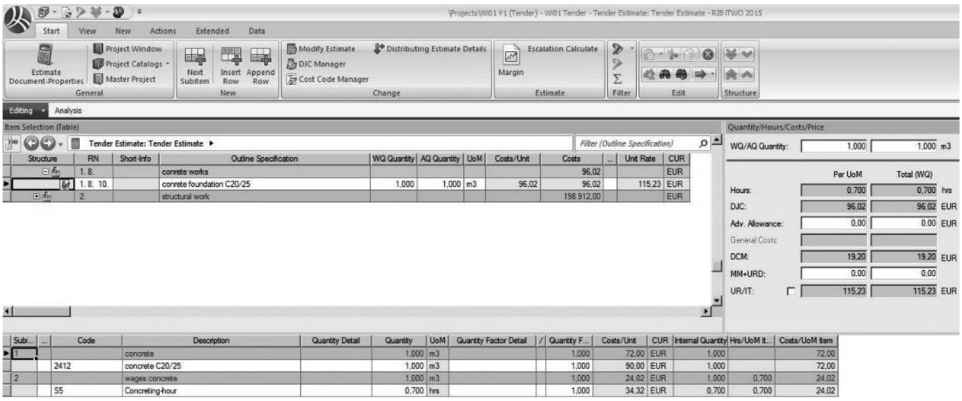

Figure 3.8 Standard item – Concrete foundation (RIB iTWO®)

- Insertion of standard item: Estimator inserts the standard item above
- Customization: The estimator adjusts required parameters as follows:
  - Costs for concrete are increased to 90 EUR / m³
  - The rate of concreting is increased to 0.8 h / m³ due to obstacles

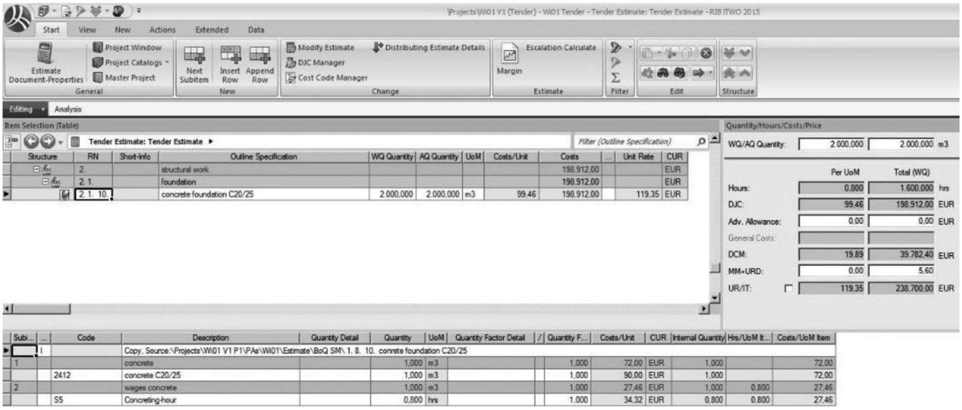

Figure 3.9 Calculation of item 2.1.10 – Concrete foundation (RIB iTWO®)

3.5.3 EDP evaluation

Due to the recourse to pre-structured, differentiated calculation master data, the estimator is now in possession of relevant and significant evaluations. Not only is the sum of calculated work hours available, but the data can also be sorted by hours and rates required for formwork, reinforcement, and concreting. In the field of civil engineering, calculations are performed with equipment modules, which contain individual consumption rates of diesel fuel, thus enabling an evaluation of diesel consumption for the project. The following list shows quantities and cost rates of calculated cost elements.

Table 3.9 Costs analysis

Item	Quantity	Unit	EUR/Unit	Costs in EUR
Concreting hours	1,084.00	h	34.32	37,202.88
Concrete C20/25	915.00	m³	90.00	82,350.00
Caterpillar 140 kW	420.00	h	45.00	18,900.00

The EDP evaluations also help the estimator with ABC analysis. The list “key items” shows sorted items by total price. Given the relevant parameters, the list shows the most cost-intensive items only, which constitute 80 % of the bid sum. Thus, this is a valuable checklist for the estimator to critically analyze the expensive items in order to ascertain if selected master data calculation approaches were adjusted towards project-specific cost estimates; see the following example:

Table 3.10 List of key items

Sum of bids: 7,750,240.00 EUR

Item	Quantity	Unit	EUR/ Unit	Costs in EUR	Percentage of total costs
1.8.10 Concrete foundation installing	12,000.00	m³	124.83	1,497,960.00	19.3%
1.7.10 Soil loosening and installing	120,000.00	m³	9.25	1,110,000.00	14.3%
1.9.17 Pipeline concrete DN300	28,000.00	m³	31.63	885,640.00	11.4%
…. …….	……	…	…….	……	….

The quality of the calculation, with respect to both differentiation of cost elements and close-to-actual cost estimates, is enhanced by master data support. The list "concreting costs" shows a detailed bid calculation and is filed with the public client before construction begins. This list is also the calculatory basis for potential post-construction work.

Table 3.11 Concreting costs

Item		Quantity	Unit			Total Unit price
1.8.10	Concrete foundation installing	12,000.00	m³			136.82 €/m³
		Quantity	*Unit*	*EUR/ Unit*	*EUR/Unit*	
	Concrete C20/25	1.00	m³	90.00	90.00	
	Concreting work hours	0.70	h	34.32	24.02	
	Sum				114.02	
	Overhead costs 20 %				22.80	
	Total unit price				**136.82**	

3.5.4 Master data organization

The master data requires a high degree of differentiation, division into operational/manufacturing processes, and comprehensive memory of prototypes for essential individual activities.

Master data should be consistently adjusted for the sections bid calculation, work scheduling, and site monitoring. Practice-oriented recourse to master data enables an economical estimating.

The basis for the total field of master data organization is constituted by the smallest information-bearing unit – called the cost element. In practice, master data memory consists of 5,000 to 10,000 cost elements, which are structured by high-level criteria in the calculation such as wages, materials, subcontractor works, and other costs. Wage-cost elements are structured by main fields of operation, and material costs should be structured in conjunction with their purchase costs. In the calculation, a large part is occupied by material cost elements and related cost rates. Figure 3.10 shows the structured cost-element hierarchy using three example material cost elements for different concrete goods.

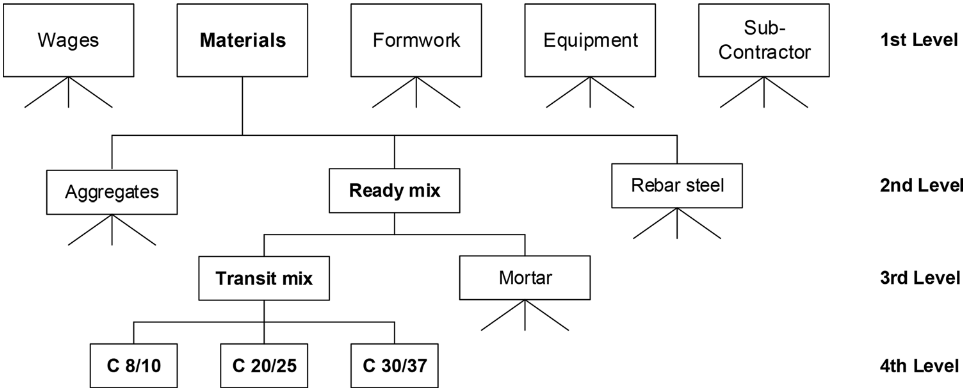

Figure 3.10 Cost-element hierarchy – Excerpt of concrete cost elements

In practice, company master data contains 5,000 to 6,000 material cost elements with fixed cost rates. Price levels of materials are memorized and allocated to region-specific market areas. Material costs, however, have to be adjusted for individual projects.

Wage cost elements are also itemized in the hierarchy. Commonly, they are structured according to fields of operation and union-rate groups respectively, for example:

- Wage cost element: Construction site setup
- Wage cost element: Excavations/earthworks
- Wage cost element: Concreting
- Wage cost element: Asphalt works
- Wage cost element: Piping works

Wage costs are usually determined using an average-wage value for the scheduled construction team meaning the same average wage is allocated to every wage cost element. The benefit of structuring different wage cost elements is that a differentiated evaluation of wage-hour sums can be performed. Hence, the estimator receives detailed information on wage-hour sums for individual operational fields, such as concreting and asphalt works, in addition to the total wage-hour sum.

Bid calculations are usually extremely pressed for time. Hence, it seems only natural to summarize or condense cost elements. The next level where items can be and are condensed is occupied by modules, which are noted in itemizations as equipment modules, in which individual cost elements, such as depreciation/interest, maintenance, fuel, lubricants, and operator wage costs are summarized in a single module. Cost rates have to be adjusted in accordance with equipment management.

The estimator can use these modules to receive any relevant detailed information in order to, for example, evaluate diesel consumption for a construction project.

Module: Excavator

Module: **R 916**	
Descr.: **Crawler excavator with backhoe**	

D+I – Depreciation and interest	Equipment
MNT – Maintenance	Equipment
Fuel + Lubricants	Material
Operator	Wage

Figure 3.11 Module – Crawler excavator

The superordinated hierarchy level is occupied by standard items where partial activities are calculated fully. The estimator can use standard-item values as recourse parameters and adjust them according to present project conditions. A tried and tested way to successfully perform master data calculations is to condense master data with the related detailed information to complete work packages - i. e. standard items. Using this method, it is important to note that a register of as few as possible but universally applicable standard items should be created so as not to bloat it unnecessarily.

Bid calculations are thus supported by master data in a significant way. The crucial part is to include all representative prototypes from the whole spectrum of processed categories in the standard calculation and, again, create prototypes in such a way that they are as universally applicable as possible so that project-specific adjustments can be performed with relative ease. In summary, standard items should exhibit the following features:

– Structure, if possible, should follow single cost-relevant criterium
– Clear assumptions for calculation
– Transparent calculation approach
– Interim calculations (e. g. for individual activities)
– Conversion factors to enable speedy adjustments
– Universal applicability

Figure 3.12 shows a standard item which includes the activites “formwork” and “concreting” with calculatory experience values. After data retrieval of this standard item, project-specific values, such as regional prices for concrete, have to be adjusted accordingly.

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