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PROBABILISTIC COST ESTIMATION FOR MAJOR CONSTRUCTION PROJECTS IN INFRASTRUCTURE

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Abstract
In 2024, multiple tenders for infrastructure projects using Integrated Project Delivery (IPD) are issued. These models have recently been introduced in Germany and Austria. They aim to reduce cost and schedule overruns on major projects. IPD uses criteria such as partnership-based project management which is based on a collaborative culture to select a contractor. Contract models, such as cost reimbursement with bonus/malus mechanisms, are used to further reduce the impact of price. However, traditional calculation is not suitable for new remuneration models as it tends to hide extra profits. It is therefore not transparent enough for the successful implementation of IPD.

The construction costs are usually determined in the award procedure by pricing a bill of quantities. However, in IPD there is no bill of quantities. Instead, the cost estimate is based on a probabilistic performance calculation by the contractor. Costs for materials and machinery are recorded separately and independently. Risk management gives the cost calculation a range. Overheads and profit are added based on pre-agreed mark-ups. A bonus/malus mechanism encourages cost reductions by the contractor. This allows transparent control by the owner or a third party. Including scientific theories, such as systems theory, probability theory, principal agent theory and hold-up problem, in the development of the model ensures maximum transparency in cost estimation.

This paper presents the basics of traditional calculation and shows the reasons why it is not suitable for estimating the costs of large construction projects. A new holistic and transparent model for probabilistic cost estimation is developed and presented. The focus is on the base costs. The paper concludes with an outlook on further research and an option of digitalization of the process transparency.

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Keywords: cost calculation, cost estimation, cost prediction, infrastructure, probabilistic.

1. Introduction

Integrated Project Delivery (IPD) is an approach for the delivery of major construction projects which supports to be in the given budget and on time [1]. IPD in general combines characteristics such as common risk management, a remuneration model like reimbursement of costs, incentive mechanism, and "open book" billing [2, 3]. Early contractor involvement, the involvement of a contractor in the early project stages, exists in different forms and is also a part of the delivery model [4]. The efficiency of IPD in regards to construction time was proven in a case study [5, 6]. The study develops a digital model to compare the construction time of a traditional contract model and an IPD. The results indicate a reduction between 14% and 22% of contraction time by using IPD [7]. Due to the high need for infrastructure renovation in Germany and Austria, IPD is being used more and more. However, IPD also fails with its application if the costs for the project are not calculated realistically (with risks and price increases) and transparently. Because IPD has no bill of quantities, the calculation must be structured differently.

2. Cost estimation and basic principles

A key element for successful project delivery is a profound and accurate cost estimation [8]. Fig 1 shows the reduction of uncertainty over the project duration with a deterministic and probabilistic approach. When the project is launched the uncertainty is the highest. Cost Estimation might be either too high or too low. As time goes by the uncertainty is reduced. The red dots symbolize deterministic cost estimations. It is obvious that these cost estimates are not exact and will only reflect a portion of the actual costs. A probabilistic cost calculation (blue dots) represents the entire range of the spectrum and is a better approach especially for major projects with many risks and uncertainty.

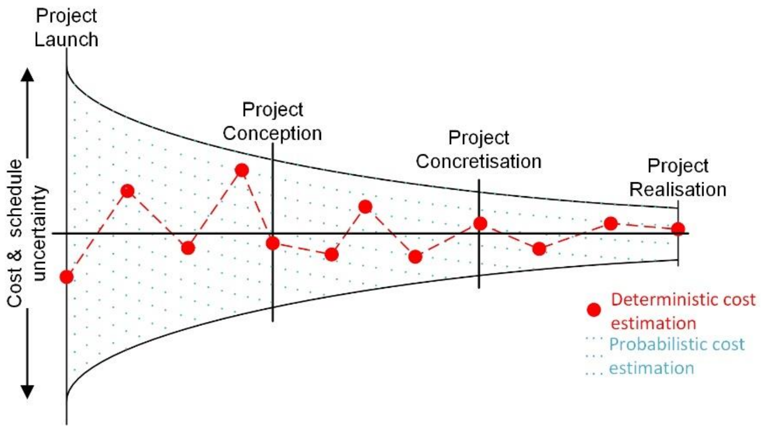

Fig 1. Reduction of Uncertainty over Project Duration [9]

German public procurement law generally stipulates that the tender offering the most cost-effective solution should be awarded the contract [10]. In practice, this translates to the selection of the lowest-priced bid. Other factors like the quality of the key personnel are not relevant. So, there is only a price fight between the bidders. Nevertheless, the tender price is an entirely unrealistic estimate of the construction costs, particularly for large-scale projects. This is precisely where IPD is a better approach. The role of price in award procedures is no longer as significant as it once was. Cause of the ECI it's not possible to calculate the cost for the project so the cost will be calculated together with all participants. To prevent further price competition, a transparent calculation process is specified, which is based on the first level between basic costs, costs for risks, and price increases in relation to the outflow of funds. Surcharges are presented in a separate section. The transparent calculation process, which is applied uniformly to all bidders, permits the focus to be placed on other award criteria.

2.1. Traditional Cost Estimation

By using traditional delivery models like Design-Build or Design-Bid-Build most of the time a unit price or firm fixed price contracts are used. These contract models have a bill of quantities and a program of quantities. So, the contractors can calculate their cost on the base of these services. In the literature, a clear cost assessment process for these delivery models is provided.

To be able to develop a new process, the existing fundamentals of the cost estimation must first be analysed. For cost estimation several techniques are available in literature [11]:

- The "analytical technique" is an activity-based costing method in which the cost of individual work items is estimated and summed up to obtain the total project cost [12,13]. The items are presented by the bill of quantities. However, the more complex a project is, the less accurate the bill is. This method is the most widely used for public tenders in the construction industry.
- The "analogical technique" of cost estimation compares a new system with a previously used one [13, 14].

- The “Parametric technique” employed involves the application of statistical techniques to establish a correlation between the historical construction costs and a selected number of pertinent project parameters [12].
- Another technique, designated as "expert systems," is a combination of various techniques, including decision trees and specialized cost estimation software, which is utilized for project cost estimation [14,15]

None of these techniques fits the requirements for transparent cost estimation in the reimbursement models. The following chapter uses the example of a technique to show why these are not suitable for IPD.

2.2. Hidden surcharges

Using traditional cost estimation techniques can work more or less well with a complete bill of quantities. However, this allows bidders to hide surcharges. Especially the analytical technique is open for misuse. Firstly, the bill of quantities is rarely complete. Secondly, surcharges, such as profit and overhead, are hidden in the items of the bill (see Fig 2, typical example for a unit price contract). A special feature of the construction industry is that construction site overheads are also allocated to the items. Therefore, the pricing is incomprehensible to outsiders.

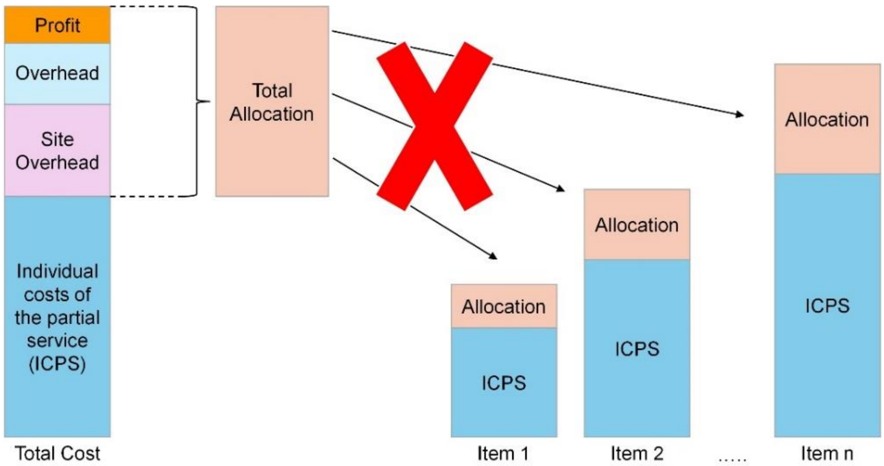

Fig 2. Surcharges distributed to items

The remuneration models in IPD, however, do not require the creation of a routing bill of quantities. As described above, on the one hand these are never complete for major construction projects, and on the other hand because they involve the possibility or obligation of concealing surcharges. Instead of pricing a bill of quantities, the costs are determined jointly by the client and the contractor. Additionally, new remuneration models are also used in IPD. Therefore, a new cost estimation process is necessary.

3. Research design and Research question

The starting point for this elaboration is the necessity for a distinct type of calculation for major construction projects in the infrastructure sector when using IPD. The necessity for new project delivery models in the construction industry is not the subject of this study but is evident due to cost and schedule overruns when using traditional delivery models.

Firstly, an in-depth literature review is carried out with several search stings on various platforms (Google Scholar, ResearchGate and Elsevier). This identifies the need for further research and the research gap. Based on this, suitable research questions are formulated. A deductive approach is chosen for further investigation.

The research gap identified is that there is no transparent cost estimation process for cost-reimbursement remuneration model as they are used in IPD. Therefore, a new calculation process is developed based on existing scientific theories. This process is evaluated in serval use cases and has already been proven by the authors. The underlying research question was: How should the cost estimation be structured so that costs can be calculated transparently at an early stage of the project without a list of quantities? Upcoming, the scientific theories will be briefly described for the flow, followed by the cost estimation process.

4. Scientific Theories

This subchapter describes the scientific theories used in the development of the new cost calculation. The system theory builds the foundation for the approach by setting a defined scope and lastly, the probabilistic theory is used to support a realistic cost estimate. The principal agent theory and the hold-up problem outlines the basic problem between the contractual relationship between the participants.

4.1. System Theory

The System theory is an interdisciplinary field of research that draws upon aspects of philosophy, sociology, cybernetics, economics, and biology. It was developed and refined following the second world war. In the context of this work, a system is defined as follows: a system is a modelled representation of the whole, consisting of interlinked elements that interact with each other and have different attributes. At the same time, a system can be differentiated from its environment [16, 17].

4.2. Probability theory

Probability theory is a branch of mathematics. It describes the likelihood an event might occur with numerical values between 0 and 1. Probability axioms, introduced by Andrey Kolmogorov in 1933, are based on the values and commonly used to express probability [18]. The application of probability theory enables the consideration of potential uncertainty [19].

4.3. Principal Agent Theory and Hold-Up Problem

A fundamental conflict of objectives in the two-party system between client and contractor is dominant. Construction companies are interested in maximizing profits, while clients are only interested in the best possible performance of services within the given framework conditions at minimum cost [20–22]. This conflict of objectives is exacerbated by an asymmetry of information in favour of the contractor. Related to the situation in construction projects to the principal agent theory, the information advantage is always exploited to one’s own advantage according to Nister [23] and Faber [20].

In addition to this theory, the hold-up problem describes a problem scenario that also occurs frequently in the construction industry: when the contract is concluded, the actual motives and motivations of the contracting parties are not known to each other, which can lead to opportunistic behavior in the ex-post contract phase. Dependencies can be exploited through the “lock-in effect” [24].

5. Probabilistic Cost Estimation Process, Goal and Principals

This chapter describes the Probabilistic Cost Estimation (PCE) model. It starts with a process overview and explains the outcome and goal of the process and the determination of the target cost. This is followed by a detailed explanation of the cost components, with focus on the base cost. A description of the necessary risk management and determination of escalation is not part of this research. At the end of this chapter the most important aspects of the base cost estimation, regarding the transparency, are summed up.

5.1. Probabilistic Cost Estimation Process

The developed methodology employed for PCE is presented in Fig 3. The process is depicted schematically in the upper part of the diagram. This diagram illustrates the chronological sequence of the process steps, from left to right and from top to bottom. The process commences with the determination of base costs and base schedule (blue), proceeds to risk analysis and mitigation planning (red and purple), and culminates in the selection of an approach for escalation (green). The results for costs and schedule are presented in the lower part of the diagram (green).

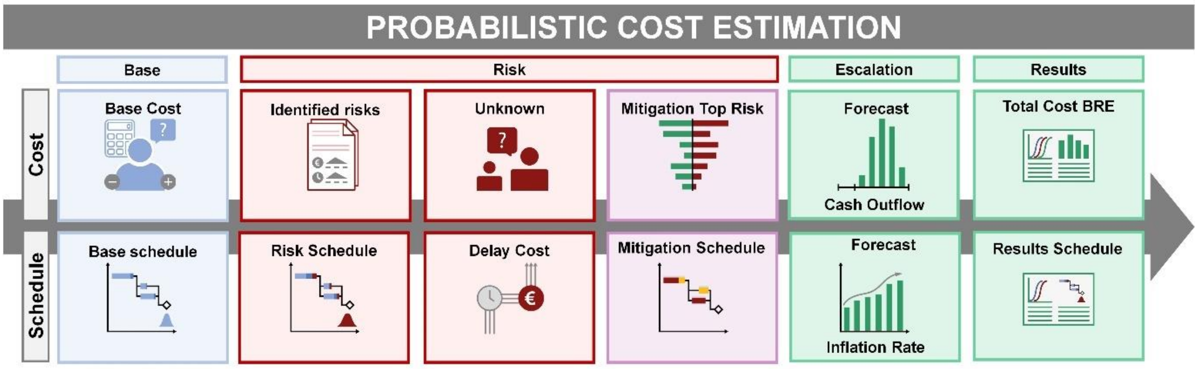

Fig 3. Probabilistic Cost Estimation Process

This paper puts the focus on the presentation of the base costs. However, for a real and complete PCS, all process steps must be processed in detail.

5.2. Cost components

The PCE requires a special kind of cost grouping. Therefore, cost components are grouped as follows (see Fig 4) [25]:

- Base Cost ("everything goes according to plan", with no reserves for risks or approaches for escalation)
- Construction Cost (Base Cost + Risk + Escalation)
- Total Cost (Construction Cost + Overhead + Profit)

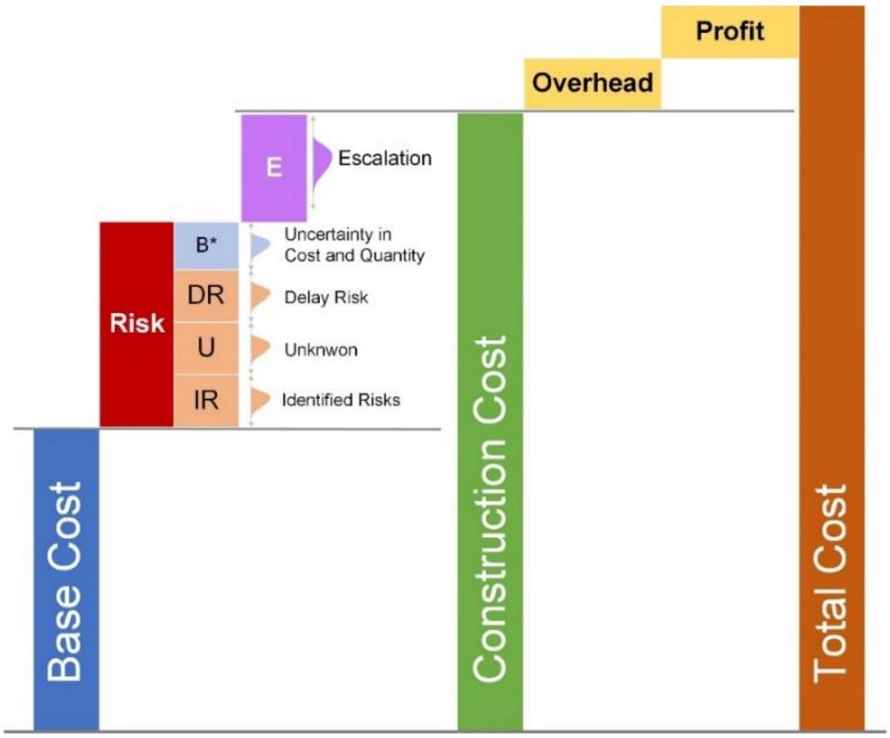

Fig 4: Cost Components in Probabilistic Cost Estimation

Base Cost means when "everything goes according to plan", with no reserves for risks or approaches for escalation (price increase). Risks are costs arising from risks and opportunities that may occur. The Identified Risks (IR) are definable threats and opportunities that have been recognized for the project and are taken into account accordingly in the remainder of the project. The Unknown (U) is calculated as a flat-rate surcharge on the base costs for unidentified and unidentifiable risks. The surcharge is calculated systematically using a Risk Fact Sheet for unknown risks [26]. This also results in a delayed outflow of funds. These are also considered during Escalation. Delay Risks (DR) are risk-related delays. These lead to a postponement of performance. This also leads to a delayed cash outflow. These are also taken into account in Escalation. Uncertainty in Cost and Quantity (B*) are deviations within the base costs that can arise due to quantity or cost uncertainties. These decrease over the course of the project. Escalation is cost resulting from the forecast price increases. Overhead encompasses all expenditures that cannot be directly attributed to a specific construction. Profit is the amount that remains from sales, or the total income of a company, after deducting all costs. The profit corresponds to the planned project result and thus serves the company to achieve the planned economic result. For the sake of transparency, general Overhead and Profit must be recognized separately [27].

5.3. Base Cost

The calculation of Base Cost is a key element for PCE. They need to be free of any surcharges. On the first level Base Cost is divided in Individual Costs of the Partial Service (ICPS) and the construction Site Overhead (SO) (see Fig 5). At the second level, a differentiation is made between costs that are time-related and time-independent. A distinction is also made between direct and indirect costs as well as time-related and time-independent costs.

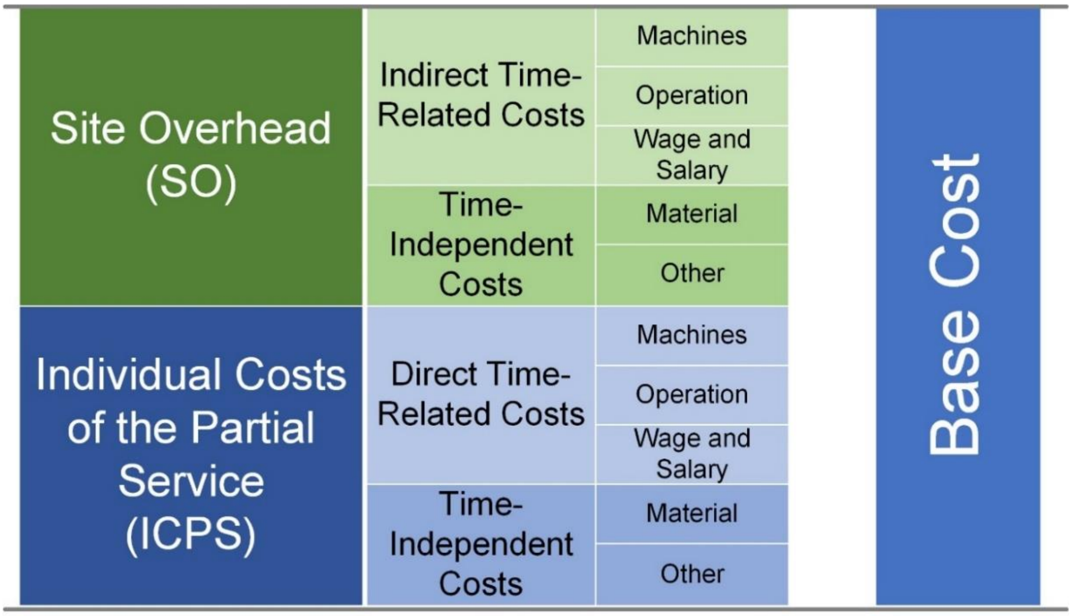

Fig 5. Components Base Cost

The ICPS are the costs that can be directly allocated to a production process. They reflect the costs of producing a product, good or service. They are divided into time-related and time-independent direct costs, as well as Machines, Operation, Wage and Salary, other direct costs. The SO are costs that arise from the production of a construction project but cannot be allocated to a production process. They are divided into time-independent and time-related indirect costs and further subdivided into equipment, operating, wages and salaries, materials and other. ICPS and SO can be further subdivided into Time-Independent Costs, Direct Time-Related Costs, and Indirect Time-Related Costs. Time-Independent Costs are costs that do not correlate with time. They include, for example, material costs. These costs are incurred, for example, when materials are consumed, but do not cause any costs if the materials are not consumed. Time-Related Costs are all running costs incurred on the construction site. These include wages, non-productive wages, equipment maintenance, monthly equipment repair costs, energy costs for lighting, ventilation, ongoing insurance and much more. These Direct Time-Related Costs can be further subdivided into Direct Time-Related Costs (ICPS) and Indirect Time-Related Costs (SO). The costs divided into Direct Time-Related Costs can, for example, be allocated to specific manufacturing processes. The Indirect Time-Related Costs cannot be directly assigned to a manufacturing process. The Indirect Time-Related Costs are determined by the duration of the critical path [28].

Allocation and grouping in the cost calculation are essential for transparency and to prevent hidden surcharges. After the calculation is done the PCE continues by connecting the Base Cost to the Base Schedule.

5.4. Benefits of PCE

The most important aspects of a transparent and therefore cost-apportionment-free probabilistic cost estimation on the part of the contractor/partner are as follows:

- A transparent presentation ICPS and SO production costs with disclosure of time-related costs.
- The ability to check for hidden surcharges that are not in the spirit of a partnership approach.
- The comparability of the approaches of the contractual partners (costs and services).
- The preparation of a schedule using realistic performance approaches (integral consideration of costs and deadlines).
- The assessment of risks based on comprehensible cost estimates, with a particular focus on time-related costs. In the award phase, the bidder is required to prepare a sample calculation of labour costs. This is intended to demonstrate to the client how transparent the bidders are in their costing approach.

6. Summary

It is shown that IPD helps to save costs and time. An additional study was conducted for this purpose. Due to the remuneration model and the early involvement of all stakeholders, a transparent cost calculation is required. The classic list of quantities and service programs are no longer available. A literature analysis showed that there is no cost calculation process for IPD. For this reason, a process was developed that initially only describes the basic costs. The transparent identification of the cost components is elementary. This also supports the subsequent billing for the client according to the "open book" principle. Finally, the advantages of PCE were presented.

7. Outlook

This paper just showed the composition of the base cost, the first step in probabilistic cost estimation. The next steps are creating the basic schedule, linking schedule and costs, risk analysis, and so on (see Fig 3). So, further research is necessary to develop a guideline. Consequently, the guideline needs to be validated with a use case. It would also make sense to support and accompany the implementation of the guidelines with software. The result would be a transparent, digital, and accessible cost estimation process. The software tool DigiCon, developed by the DigiPeC Project, is one option for the digitalization of the PCE [29].

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References

[1] S. C. Becker and C. P. Friedinger, "Analyse potenzieller Vergütungsmodelle und Anreizsysteme für die Integrierte Projektabwicklung (IPA)," 2023, doi: 10.17185/duepublico/79139.

[2] S. C. Becker and H. Roman-Müller, *Integrierte Projektabwicklung (IPA): Schnelleinstieg für Bauherren, Architekten und Ingenieure* (essentials). Wiesbaden: Springer Vieweg, 2022.

[3] S. C. Becker and C. P. Friedinger, "Application of Alternative Contracting Methods for Large Infrastructure Projects as example Project Alliancing ," in *Sustainable Mobility Infrastructure (Porto, 2022)*, Porto, ICPMA, Ed., 2022.

[4] C. P. Friedinger and S. C. Becker, "Early Contractor Involvement für öffentliche Auftraggeber – Chancen für eine effizientere Projektabwicklung," 2023, https://doi.org/10.17185/duepublico/79115.

[5] C. P. Friedinger, K. Mitteregger, and P. Sander, "Probabilistic Analysis of the Delivery Models Unit Price and Alliance applied at the Project Gemeinschaftskraftwerk Inn with Focus on the Construction Time," in *Proceedings of the ISRM 15th International Congress on Rock Mechanics and Rock Engineering & 72nd Geomechanics Colloquium: Challenges in Rock Mechanics and Rock Engineering*, Salzburg, Austria, W. Schubert and A. Kluckner, Eds., 2023, pp. 202–207.

[6] C. P. Friedinger, P. Sander, S. C. Becker, and T. Villinger, *Analyse und Gegenüberstellung der Vortriebsdauern von Einheitspreisvertrag und Allianzvertrag beim Druckwasserstollen des Projektes Gemeinschaftskraftwerk Inn: Forschungsbericht*. Neubiberg, 2023. [Online]. Available: https://athene-forschung.unibw.de/?id=144664

[7] C. P. Friedinger, S. C. Becker, and P. Sander, "Research and comparison of delivery models at the Gemeinschafts Kraftwerk Inn," *Geomechanics and Tunnelling*, vol. 17, no. 3, 2024, doi: 10.1002/geot.202400008.

[8] P. E. D. Love, X. Wang, C. Sing, and R. L. K. Tiong, "Determining the Probability of Project Cost Overruns," *J. Constr. Eng. Manage.*, vol. 139, no. 3, pp. 321–330, 2013, https://doi.org/10.1061/(ASCE)CO.1943-7862.0000575.

[9] P. Sander, "Risikomanagement bei Großprojekten im Tunnelbau," in *Handbuch Tiefbaurecht* (C. H. Beck Baurecht), B. Fuchs, M. Maurer, and G. Schalk, Eds., München: C.H. Beck, 2022, pp. 691–715.

[10] Deutscher Bundestag, *Gesetz gegen Wettbewerbsbeschränkungen: GWB*.

[11] A. Hannan, A. Ahmed, T. Ashraf, and Q. Bai, "Estimation of Highway Project Cost using Probabilistic Technique," *dtetr*, ictim, 2017, https://doi.org/10.12783/dtetr/ictim2016/5523.

[12] D. Makovšek, "Systematic construction risk, cost estimation mechanism and unit price movements," *Transport Policy*, vol. 35, pp. 135–145, 2014, https://doi.org/10.1016/j.tranpol.2014.04.012.

[13] P. Duverlie and J. M. Castelain, "Cost Estimation During Design Step: Parametric Method versus Case Based Reasoning Method," *The International Journal of Advanced Manufacturing Technology*, vol. 15, no. 12, pp. 895–906, 1999, https://doi.org/10.1007/s001700050147.

[14] G. Molcho, A. Cristal, and M. Shpitalni, "Part cost estimation at early design phase," *CIRP Annals*, vol. 63, no. 1, pp. 153–156, 2014, https://doi.org/10.1016/j.cirp.2014.03.107.

[15] F. R. Dagostino, L. Feigenbaum, and C. Kissoon, *Estimating in building construction,* 2nd ed. Toronto: Pearson Prentice Hall, 2008. [Online]. Available: https://archive.org/details/estimatinginbuil0000fran/page/n5/mode/2up

[16] I. Giesa, *Prozessmodell für die frühen Bauprojektphasen* (Zugl.: Darmstadt, Techn. Univ., Diss., 2010) (Schriftenreihe des Instituts für Baubetrieb / Institut für Baubetrieb <Darmstadt> D 54). Darmstadt: Inst. für Baubetrieb, 2010.

[17] I. Jahnke, T. Herrmann, and S. Metz-Göckel, *Dynamik sozialer Rollen beim Wissensmanagement*. Wiesbaden: DUV, 2006.

[18] B. Lauth and J. Sareiter, *Wissenschaftliche Erkenntnis: Eine ideengeschichtliche Einführung in die Wissenschaftstheorie,* 2nd ed. Paderborn: mentis, 2005. [Online]. Available: http://www.mentis.de/download.php?media_id=00003655

[19] P. Sander, *Probabilistische Risiko-Analyse für Bauprojekte: Entwicklung eines branchenorientierten softwaregestützten Risiko-Analyse-Systems* (Zugl.: Innsbruck, Univ., Diss., 2012), 1st ed. Innsbruck: innsbruck univ. press, 2012.

[20] S. Faber, *Entwicklung eines Partnering-Modells für Infrastrukturprojekte: Ein Beitrag zur Optimierung der Abwicklung von Bauprojekten im öffentlich finanzierten Infrastruktursektor in Deutschland* (Zugl.: Kassel, Univ., Diss., 2013) (Schriftenreihe Projektmanagement 17). Kassel: Kassel Univ. Press, 2014.

[21] S. C. Becker and P. Sander, "Development of a Project Objective and Requirement System (PORS) for major infrastructure projects to align the interests of all the stakeholders," in *Expanding Underground - Knowledge and Passion to Make a Positive Impact on the World: Proceedings of the ITA-AITES World Tunnel Congress 2023 (WTC 2023), 12-18 May 2023, Athens, Greece*, G. Anagnostou, A. Benardos, and V. P. Marinos, Eds., Erscheinungsort nicht ermittelbar: Taylor & Francis, 2023, pp. 3369–3376.

[22] S. C. Becker, "Identifizierung von Anreizen in Verträgen nach der VOB/A-EU unter Einbezug von der VOB/B," in *Tagungsband zum 31. BBB-Assistent:innentreffen Innsbruck 2022: Fachkongress der Wissenschaftlichen Mitarbeiter:innen Bauwirtschaft, Baubetrieb, Baumanagement, Tunnelbau : Beiträge zum 31. BBB Assistent:innentreffen vom 12. bis 14. Juli 2022 in Innsbruck*, Arbeitsbereich Baumanagement, Baubetrieb und Tunnelbau, Ed., Innsbruck: Studia Verlag, 2022, pp. 16–29.

[23] O. Nister, *Die baubetrieblichen und bauökonomischen Aspekte des Vertragswesens der Projektentwicklung aus der Sicht „Unvollständiger Verträge“* (Zugl.: Dortmund, Univ., Diss., 2005). Dortmund, 2005.

[24] A. Picot, H. Dietl, and E. Franck, *Organisation: Eine ökonomische Perspektive,* 1st ed. Stuttgart: Schäffer-Poeschel, 1998.

[25] S. C. Becker, C. P. Friedinger, and P. Sander, "Risk Management and Contract Models in Tunnel Construction –: Part 1: Basics of Risk Management," *tunnel*, no. 01, pp. 22–28, 2024.

[26] P. Sander, S. C. Becker, and Friedinger, Spiegl, MarkusCarl Philipp, "[Duplikat] Risk Management and Contract Models in Tunnel Construction – Part 2: Integral Consideration of Cost, Schedule, and Risks," *tunnel*, no. 02, pp. 24–29, 2024.

[27] P. Sander, S. C. Becker, C. P. Friedinger, S. Riemann, M. Ditandy, and M. Spiegl, "Risikomanagement bei Großprojekten im Tunnelbau: Teil 3: Gestaltung von Anreizmechanismen für die Integrierte Projektabwicklung," *tunnel*, no. 04, pp. 12–23, 2022.

[28] P. Sander and S. C. Becker, "Gemeinsames Risikomanagement bei Großprojekten mit der integrierten Projektabwicklung (IPA)," in *DVP-Tagung 2023*, Berlin, Deutscher Verband für Projektmanagement in der Bau- und Immobilienwirtschaft e. V., Ed., 2023, pp. 1–27.

[29] C. P. Friedinger and P. Sander, "Development of an early contractor involvement selection tool for public owners," in *TUNNELLING FOR A BETTER LIFE: Proceedings of the ITA-AITES World Tunnel Congress 2024 (WTC 2024)*, Shenzhen, China, 2024, pp. 3600–3607, https://doi.org/10.1201/9781003495505-477.