INCENTIVE MECHANISM FOR IPD WITH MULTIPARTY CONTRACT BY USING A PROBABILISTIC COST AND RISK SOFTWARE

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Abstract

Participants of major projects have different interests in each tunnel project. A solution is to align the interests using the Integrated Project Delivery (IPD) with an incentive and multiparty contract (MPC). There is no paper in the literature on how to design an incentive for MPC. Starting with a deductive approach, an incentive where all participants benefit the same is designed. An inductive approach is used for validation. Furthermore, for the inductive approach, a risk software tool is used, and a separately developed Excel sheet. Finally, the mechanism's mode of action is presented and validated.

Introduction

Significant cost and schedule overruns in major projects especially in tunnel construction show that risk management is often not given the importance and necessary integration in project management that it should have (Flyvbjerg 2014). To be able to measure and control costs as well as deadlines against the defined targets, it is necessary to assess costs and risks transparently and take them into account appropriately. Nevertheless, especially in tunnel construction, there are always unforeseen and unknown risks that make this difficult.

To align the interests of all stakeholders seems like an unrealizable task. The reason is that the interests are so different. The owner aims to finish the project as soon as possible whereas the contractor is willing to do almost anything to maximize his profit. Given these almost conflicting interests, it takes all the more effort to complete tunneling projects on time and within budget. The traditional contract format fixed price transfers risks from the owner to the construction company (Becker 2022). However, the result is a high potential for claims. As described in the beginning the solution is to align the interests of all the participants and a good way to do that is an incentive contract.

Integrated Project Delivery (IPD) is used for major projects to align these objectives. Therefore, a multiparty contract is used. This means that the risks are shared and there is also an incentive mechanism to align the objectives of all parties involved.

Since there's no sufficient research on incentive mechanisms for IPD, this article will show how an incentive mechanism can be developed, and in which all participants participate in the project in proportion to their direct project costs.

To this end, the basics of IPD, multiparty contracts, and incentive contracts are first outlined. The research gap is highlighted and the software tool used for cost and risk calculation is introduced.

The description of the development of an incentive mechanism for MPC follows. First, it is described using a deductive approach.

The deductive description is succeeded by an example tunnel project (inductive). This example project is used to validate the theoretical concept.

Integrated Project Delivery (IPD)

The basic idea of IPD is to enable better handling of major projects. The aim is to achieve a faster and cheaper construction process while increasing quality. With this form of execution, an integrated execution team consists of at least the client, planners, and construction companies. They work cooperatively and project-related. All those involved in the project should be aware of the client's objectives from the outset and jointly develop project goals so that everyone involved is aware of the project requirements, and the best possible solutions to achieve the set objectives (Cheng et al. 2019).
To be able to consider identifiable risks and implement solutions cost-effectively in the planning phase, all available knowledge has to be taken into account (Warda 2019).

The core principles for IPD can be stated as follows (Ahmad et al. 2019):

- Early Contractor Involvement of core stakeholders: client, contractor, and planner prior to the start of planning (Friedinger and Becker 2023),
- joint risk management,
- incentive mechanism,
- collaborative working methods,
- joint decisions and
- conflict management.

In the following, the function of a multiparty contract is described in order to better understand the function of the delivery model.

Multiparty contract (MPC)

A multiparty contract is a contract between at least three parties: owner, planner, and construction company. This means that all parties involved in construction and planning are bound together by a uniform contract with each other. In addition, other project participants such as specialist planners, specialized finishing trades, subcontractors, or independent consultants can be included in the contract.
The multiparty contract also promotes cooperation in terms of liability and combines innovations. The incentive

contract realizes a corresponding alignment of goals between the parties. To achieve the alignment the incentive of the MPC must be designed in a way that everybody participates according to the contribution regarding the total costs of the project.
The incentive mechanism for the use case is shown below. The success of an IPD depends largely on the correct choice of the target cost. This must be done individually based on the results of the probabilistic risk analysis and the integral consideration of cost and schedules (Sander et al. 2022, Becker and Roman-Müller 2022).

Focus on Cost Plus Incentive Fee

A Cost Plus Incentive Fee (CPIF) is used when an objective relationship can be established between the fee and performance measures such as actual costs, delivery dates, and performance benchmarks. In the case of highly uncertain and speculative construction projects, it's necessary to use this kind of contract. The owner assumes the risks inherent in the contract-benefiting if the actual cost is less than the expected cost-losing if the work cannot be completed within the expected cost of performance (Becker and Sander 2023; Kerzner 2022).

Explorative Literature Analysis for finding the research gap

By using Google, Google Scholar, Scopus, and Opac+ UniBw an explorative literature analysis was made.

The search strings for this were:

- Incentive mechanism for multiparty contract
- Multiparty contract and incentive mechanism
- Incentive Mechanism for IPD
- IPD and Incentive Mechanism

Different approaches to incentive design were found during the research. These ranged from blockchain applications to theories regarding incentive design.
However, it was not possible to find a concrete implementation of an incentive mechanism for the IPD using an MPC. Therefore, there is a research gap in the area of incentive design for MPCs.
After finding the research gap the basics for the cost and risk calculation will be described. This will be later on needed for the description of the deductive and inductive approach.

Integral Modelling of Cost, Deadlines, and Risks

Cost Components

The use of cost components that build on each other aims to create cost transparency by specifying a clear cost structure that can be applied from an early planning stage to construction completion. The main cost components are (Sander and Becker 2023):

- Base Cost (B): Cost if „everything goes according to plan", without reserves for risks or approaches for escalation (price increase).
- Risk (R): Cost resulting from threats and opportunities that can occur but are not certain to occur (probability of occurrence).
- Escalation (E): Cost resulting from the forecast price increase.
- General Business Expenses (GBE): Include all costs that cannot be directly allocated to this specific construction contract but are incurred by the company as a whole.
- Profit (P): Amount that remains from sales - i.e. the total income of a company - after deducting all costs.

The sum of Base Cost, Risk, and Escalation are the direct project costs (DPC) (1).

$$DPC = B + R + E \qquad (1)$$

The sum of the DPC with the general business expenses and the profit is the Target Cost (TaC) (2).

$$TaC = DPC + GBE + P \qquad (2)$$

RIAAT (Risk Administration and Analysis Tool)

Description of the Software Application

Risk Administration and Analysis Tool (RIAAT) is a desktop application and therefore a stand-alone application.

RIAAT was developed to manage and integrate cost, risk, and schedule analysis for large-scale construction projects.
RIAAT considers the interdependence of cost and schedule. Time-related costs, risk impact, incentive fees, etc. are factored in to optimize your project in terms of cost and schedule (Sander et al. 2021; RIAAT 2024). The benefits of RIAAT are:

- Build a schedule including risks and uncertainties.
- Link schedule and cost using drag-and-drop.
- Consider cost caused by schedule risks.
- There's never only one critical path. Takes every option into account with multiple critical paths.

Figure 1 shows the connection between Cost, Risk, and Schedule and the result as an example of the delay cost.

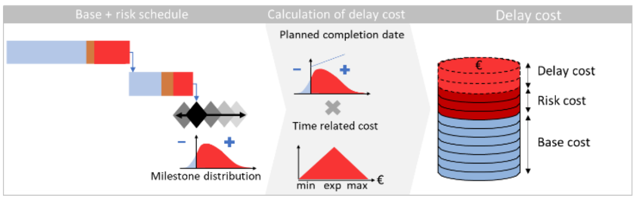

Figure 1: Example integrated calculation of delay cost (RIAAT 2024)

RIAAT bases the decisions on the best risk-benefit ratio shown in Monte Carlo simulations creating probability distributions that allow you to assess the level of probable cost or time overruns with regard to your defined budget or milestone date.

The benefits are:

- Consider uncertainties at all levels.
- Use ranges (bandwidths) instead of single deterministic numbers, and
- Bottom-up aggregation for transparent results.

Both in the business and financial sector and in the construction industry, a statistically determined fractile value of the value at risk (VaR) is used to quantify this monetary sum. To determine this fractile value, a certain probability value must be set depending on the assessment of the complexity of the project and the risk appetite or risk acceptance (Bergmeister 2021; Bergmeister 2022).

With X as a variable with the distribution function (3).

$$F_x(x) = P(X \leq x) f\text{ür } x \in \mathbb{R} \qquad (3)$$

Random losses are represented by the positive values of the random variable X inverse of the distribution F_X^{-1} and the confidence level with $\alpha \in (0,1)$.
The VaR will be defined in (4) (e.g. Figure 2).

$$VaR_\alpha(X) = F_X^{-1}(\alpha) \qquad (4)$$

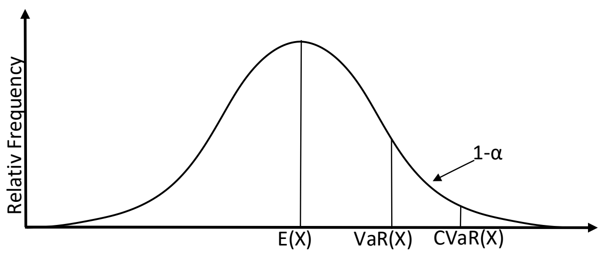

Figure 2: Value at Risk

Deductive Approach for Designing the MPC Incentive

Accordingly, it is important to design the incentive for the MPV in such a way that everyone participates equally in this contract. This means that everyone participates in the potential bonus according to their share of the production costs of the project. The following is an example of how the DPC are jointly pooled and how the bonus is subsequently shared.
Figure 3 shows all contractual partners (CP). The representation of CP 1 to CP 3 refers to the Owner. The client is not considered further in this example, as it is assumed that the client does not contribute to the costs with the MPV. First, each contractor determines its DPC. As mentioned above, this is done using probabilistic methods and in the form of a work calculation.

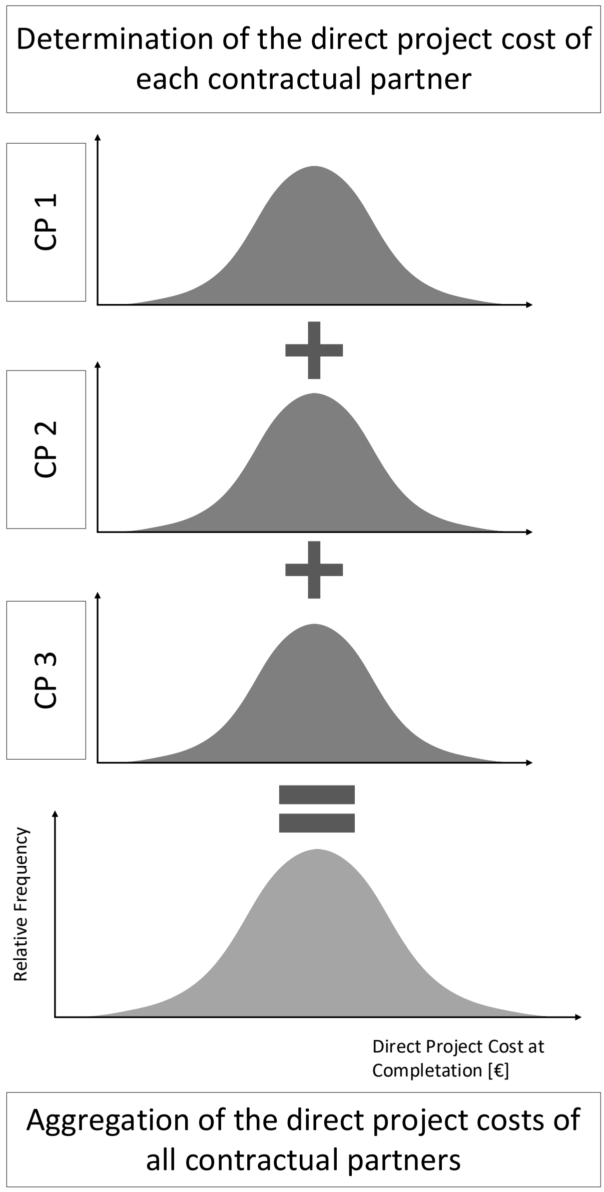

Figure 3: Determining the manufacturing costs of all contractual partners

Once the DPC for the individual contract partners have been determined, the functions (in this case three, e.g. Figure 3) are aggregated. This creates a function for the manufacturing costs. All contract partners must then decide on a P-value for the DPC. Figure 4 shows a distribution and a P-value of 50. This stands for a probability of 50% (P50) that the budget will be underrun. Conversely, there is a 50% probability that the budget will be overrun.

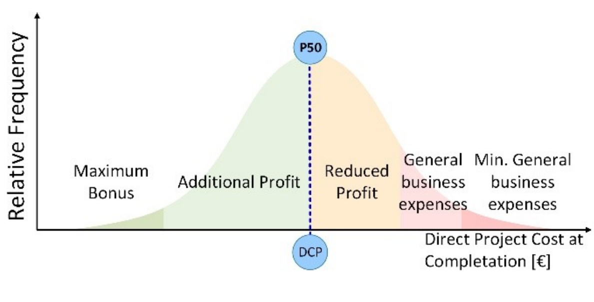

Figure 4: Determination of the P-value of the individual contractual partners

Once the P value has been set, the TaC can be assigned again for all CPs. Involved in the TaC are the GBE and P. This develops the incentive mechanism for the CPs.

Figure 5 depicts an incentive mechanism. The horizontal axis shows the potential final costs for the client, and the vertical axis shows the compensation of the contractor. The light blue dashed line shows the owner/contractor share-ratio. In this example, the ratio was set at 50/50 across all areas. This means that if the TaC is undercut or exceeded, the deviation is split equally between the two partners. Additionally, Figure 5 shows the target cost and the target profit. Both are set in the contract.

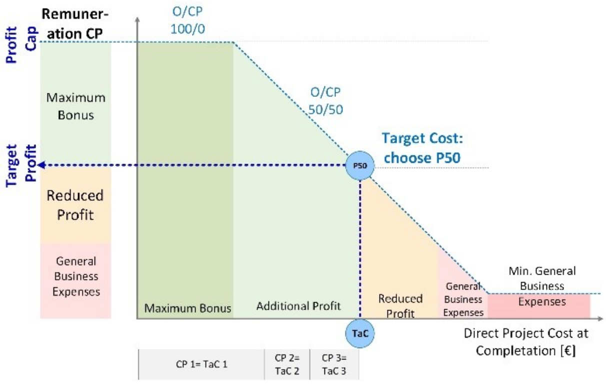

Figure 5: Aggregation of distributions and determination of target costs

Once the construction work has been carried out and the construction project has been completed, billing can take place (theoretical). Figure 6 compares the actual Construction Costs (CC) with the previously calculated DPC and the real TC. Below the horizon line is the area of the DPC.

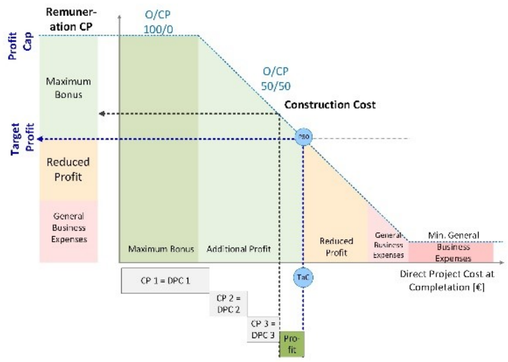

Figure 6: Settlement and distribution of the bonus

Figure 6 shows a scenario at the end of the project in which the Construction Cost (CC) is lower than the agreed TaC. Due to the lower CC, the grey dashed line shifts to the left. This can be achieved by, for example, increased efficiency, the use of new, innovative construction methods, etc. In this case, the contractor generates a bonus of 50% of the savings in addition to the target profit (increased profit). The remaining 50% of the savings goes to the client (Becker and Sander 2023).

Use Case – Tunnel Project

Project Description

A fictitious sample project in this paper is used to illustrate the process. It is based on experience from major European railway base tunnels. This 14-km twin-bore tunnel consists of several Tunnel Boring Machine (TBM) drives as well as Drill & Blast (D&B) drives in different geological formations, an access shaft, emergency stops, various cross cuttings, and inner linings. The project is separated into five lots. Lot 0 is for the access road construction, lot 1 is for the crosscut and the New Austrian Tunneling Method (NATM), lot 3 is for the access shaft, and lot 4 is for the underground refuge. So for the example project are four contractors needed. Lot 0 is not considered any further in the project description. It is no longer relevant in the consideration.

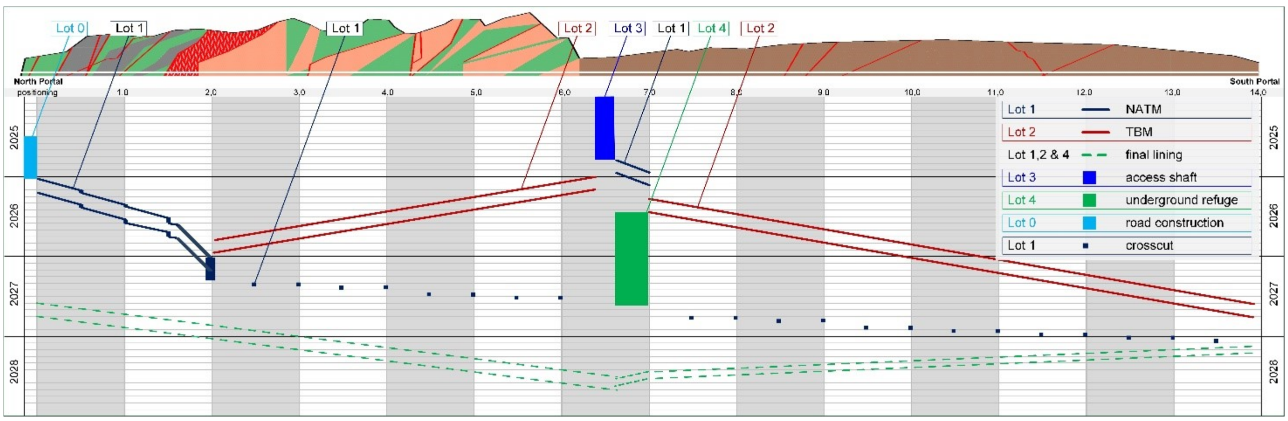

Figure 7: Path-time diagram fictional tunnel project

Inductive Approach

After the description of the deductive approach in the section above, this section shows the inductive approach by using a fictitious tunnel project. The IPD is applied with an MPC. The remuneration model is a cost-plus incentive fee. The authors created a fictitious tunnel and determined the base costs, risks, and price increases. The information was determined in a workshop and validated and adjusted accordingly by the third author. The data was entered into the RIAAT software and analyzed probabilistically. In the process, 35 risks have been included in the model as examples. The individual lots were evaluated using another specially developed Excel sheet.

The DPC (production costs) were determined for lots 1-4 and a VaR of 50% was set. After determining the DPC the GBE and the P, together a percentage premium of 8%, were multiplied by the aggregated DPC. The calculation of the DPC, the TaC, Savings, and bonus allocation are shown below.

Description of the procedure for a MPC

First, the DPC of all parties of the multiparty contract are calculated. In our case, there are four contractors. The direct project costs are composed of the base costs, risks, and price increase (Sander and Becker 2023).

Together with the determination of the direct project costs distribution functions are created, one for each member of the multiparty contract (e.g. Figure 8). Then, the P-values of the contractual partners are determined. The P-value indicates the probability of the target costs occurring. For public construction projects, as is almost always the case in tunnel construction, this value is between 50% (P50) and 90% (P90) (e.g Bergmeister 2021).

In Figure 8, the P-value was set to P=50 for this example. So, the direct project costs are for Contractor Lot 1: 90.3 Mio. €, Contractor Lot 2: 375.9 Mio. €, Contractor Lot 3: 11.1 Mio €, and Contractor Lot 4: 25.7 Mio. € (see also Table 1). The calculation was done with the software RIAAT and included all costs, risks, price increases, extra costs for schedule delays, and so on.

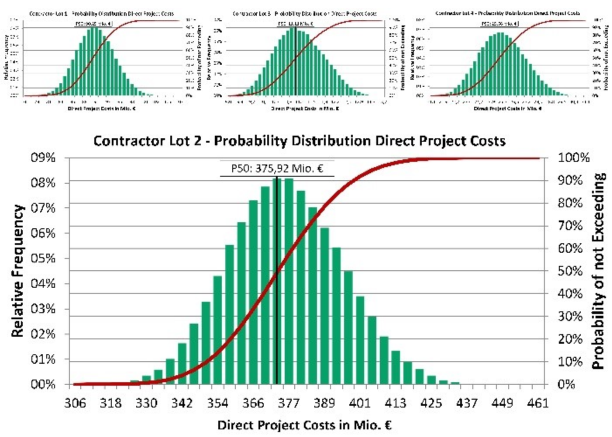

Figure 8: Distribution functions of direct project costs for each contractor

The direct project costs are determined by all members of the multiparty contract or all contractors and the client. In this example, the contractual partners would set the direct project costs at 502.9 Mio. € by aggregating all contributions of all participants.

In the next step, the TaC for the project is defined jointly and the incentive mechanism is set. In this use case, the owner and the contractors decided to add 8% to the Direct Project Cost, 5% for General Business Expenses, and 3% for Profit. The jointly agreed 8% is added to the aggregated distributions and the Target Cost is set on P50 at 543.43 Mio. € (see Figure 9). This later serves as the basis for billing.

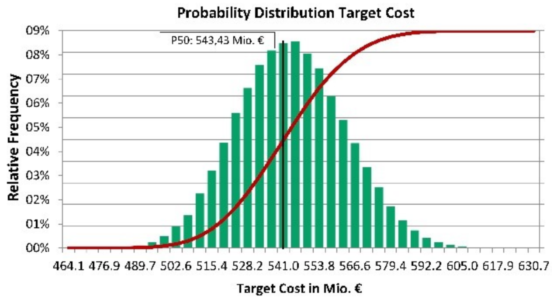

Figure 9: Probability Distribution Target Cost

Table 1 shows all the results of the example project. As described above, the VaR was set at 50%. The distribution between the client and contractor is 50/50. For example: if €5 million is saved, the client would receive €2.5 million and the contractors would also receive €2.5 million. The Target Cost was described previously. The table also shows jointly agreed DPC in Mio. €, the share of each contractor of the DPC and the agreed general business expenses and profit. This is the foundation for the Target Cost. The CC and the cost of GBE, and Profit based on the TaC are shown as well. Together, they form the Total Cost (ToC) in Mio. €. Also, the savings regarding the DPC are depicted in € and as a percentage. Finally, the table shows the share ratio, the bonus in millions for every contractor, and the bonus share of each contractor regarding their specific Target Cost.

Table 1: Costs and Savings for the Example Tunnel Project

	Contract Lot 1	Contract Lot 2	Contract Lot 3	Contract Lot 4	∑ and Share Owner
Direct Project Costs P50 in Mio. €	90,25	375,92	11,11	25,66	**502,94**
Share of Direct Project Costs in %	*17,9*	*74,7*	*2,2*	*5,1*	*100,0*
General Business Expenses and Profit in %	*8,00*				
General Business Expenses and Profit in Mio. €	7,26	30,26	0,89	2,07	**40,48**
Probability Target Cost	*P50*				
Target Cost in Mio. €	97,52	406,18	12,01	27,72	**543,43**
Construction Costs in Mio. €	89,31	373,55	10,91	24,09	**497,86**
General Business Expenses and Profit based on Construction Costs in Mio. €	7,14	29,88	0,87	1,93	**39,83**
Total Cost in Mio. €	96,45	403,43	11,78	26,02	**537,69**
Savings in Mio. € regarding Direct Project Costs	0,95	2,37	0,20	1,56	**5,08**
Savings in % regarding Contractors Direct Project Costs	*1,05*	*0,63*	*1,80*	*6,10*	***1,01***
Share Ration Savings Owne/Contractor	*50/50*				
Bonus in Mio. €	0,46	1,90	0,06	0,13	**2,54**
Bonus in % regarding Target Cost	*0,47*	*0,47*	*0,47*	*0,47*	*0,47*

(5) shows how to calculate the Direct Project Cost (DPC) for all four contractors in the use case.

$$\sum DPC_{c1-c4} = DPC_{c1} + DPC_{c2} + DPC_{c3} + DPC_{c4} \quad (5)$$

To get the percentage share for any contract (P_{DPCci}) of the DPC see (6).

$$P_{DPCci} = \frac{DPC_{Ci}}{\sum DPC \times 100} \quad (6)$$

With (7) the total of percentage of GBE (P_{GBE}) and contractor Profit (P_{CP}) is calculated.

$$P_{GP} = P_{GBE} + P_{CP} \quad (7)$$

The premium of General Business Expenses (GBP) and Profit can calculate with (8).

$$GBP_{\sum} = DPC_{ci} \times P_{GP} \quad (8)$$

Now, to calculate the Target Cost (TaC) of the project the sum of the DPC is multiplied by sum of the percentage of the GBE and Profit.

$$TaC = \sum DPC_{c1-4} \times [1 + (GBE + P)] \quad (9)$$

The calculation of the Target Cost of each Contractor (S_{TCci}) is shown in (10).

$$S_{TCci} = TaC \times \frac{P_{DPCci}}{100} \quad (10)$$

After the calculation for the project is done, the construction phase of the project follows, and at the end the billing. The contractors will receive the Construction Cost (CC) which are occur in reality. The calculation for the total CC can be seen in (11).

$$\sum CC_{c1-4} = CC_{c1} + CC_{c2} + CC_{c3} + CC_{c4} \quad (11)$$

Now, to get the Total Cost (ToC) of the project the CC are multiplied by the GBE and Profitas shown in (12).

$$ToC = \sum CC_{1-4} \times \left(1 + \frac{P_{GP}}{100}\right) \quad (12)$$

The savings of the different contracts can be calculated by subtracting the CC from the DPC for each contractor (e.g. 13).

$$Sa_{ci} = DPC_{ci} - CC_{ci} \quad (13)$$

To get the savings in percentage for each lot, divide the Savings (Sa_{ci}) and the DPC_{ci}.

$$P_{Saci} = \frac{Sa_{ci}}{DPC_{ci}} \times 100 \quad (14)$$

At the end of the project, the bonus needs to be shared between all contractors. (15) shows the formula. With Sa_{ci}, the percentage of each contractor's P_{DPCci}, and the Share Ratio (SR) the bonus can be calculated.

$$Bonus_{ci} = \sum Sa_{ci} \times P_{DPCci} \times \frac{SR}{100} \quad (15)$$

Finally, the percentage of the Bonus P_{Bonus} results from each $Bonus_{ci}$ in relation to the Target Cost of each contractor (TaC_{ci}) (e.g. 16).

$$P_{Bonus} = \frac{Bonus_{ci}}{TaC_{Ci}} \times 100 \quad (16)$$

As this is an example project, it was assumed that only around 50% of the risks occurred in the example project. As a result, the contractors and the client were able to generate cost savings of €5.08 million. Due to the 50/50 split, €2.54 million is distributed among the contractors involved. The distribution key for the bonus payment depends on the participation of the Targets Cost. Contractor Lot 1, for example, has a share of the target costs of 17.9%. Therefore, his share of the bonus is also 17.9 %. Consequently, Contractor Lot 1 receives € 0,46 million. The distribution of Contractor Lots 2-4 is equivalent.

The distribution of the bonus in % about the target cost is thus equally distributed among all participants. Each one of them has a bonus share of approx. 0.47 % of his TaC. This clearly shows that all participants in the project participate equally in the bonus of the project and thus an actual target alignment between all participants takes place.

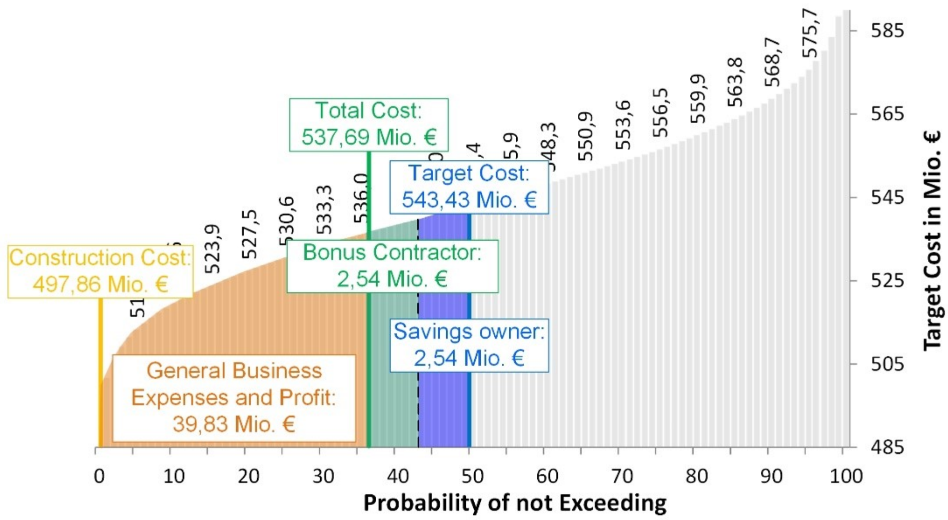

Figure 10: Results of the example construction project with a Lorenz Curve

Figure 10 shows the results with a Lorenz curve. The TaC are 543.43 Mio. € (P50) and were calculated together. The Construction Cost shows the cost that accrued for the tunnel project. The Total Cost are the cost, that the owner has to pay for the construction project (here 537.69 Mio. €). It includes the Construction Cost (here 497.86 Mio. €). and general business expenses as well as profit (here 39.83 Mio. €). In this example, the contractors' bonuses are not included in the Total Cost.
The shares of the savings and bonus are presented in more detail in Figure 11.

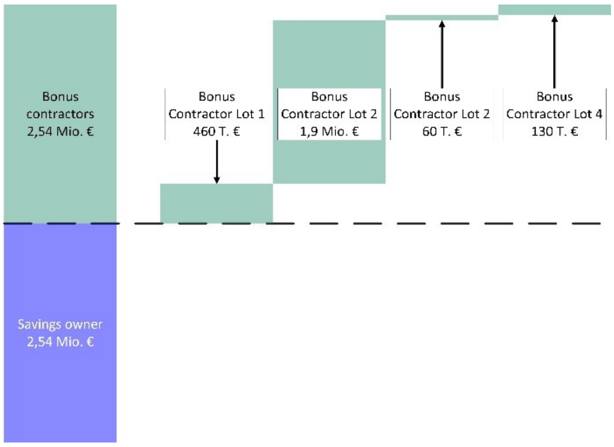

Figure 11: Shares of Savings and bonuses for the example project

According to the share ratio, the savings are split 50/50. The owner gets € 2.54 million and the contractors get the share the same amount among themselves. Every contractor gets his share according to equation (15). The calculation for Lot 1 is as follows (17).

$$Bonus_{c1} = 5.08\ Mio.€\ x\ 17.9\%\ x\ \frac{50}{100} = 460\ T.€ \quad (17)$$

The calculations for the other lots are equivalent.

Conclusions

This paper shows the application of risk software for creating an incentive mechanism for the IPD with MPC. The deductive process was validated with an inductive process to check whether the incentive mechanism treats all parties equally.
The example tunnel with several lots and the use of IPD, a cost-plus incentive fee contract, and a multi-party contract were used to demonstrate the use of the software. An incentive system was developed for a multi-party contract whereby all parties involved can participate in the success of the project. This aligns the interests of all parties involved and they work together for the success of the project. By linking the incentive to the respective parties, everyone is always obliged to do their best for the project. A multi-party contract with a cohesive incentive mechanism between all parties therefore leads to joint project success.

Outlook

Incentive mechanisms can be designed in a variety of ways. Currently, the literature generally lacks simple considerations on how all parties participate equally in an MPC. This is particularly important, as otherwise, not all parties will work in the best interest of the project goals. This simple example shows an incentive mechanism for multi-party contracts in which all parties participate equally. In order to further validate the results, further use cases need to be created and the incentive effect needs further investigation. In addition, an application should be used in a large-scale project and the results should be shared and further optimizations incorporated into the research. This would further improve the mechanism of action on the one hand and on the other hand the design of the incentive mechanism.

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