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TRANSFORMATION OF ADVANCED CONTRACT TYPES FOR THE SHIPBUILDING INDUSTRY WITH RISK ANALYSIS

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Summary

Many shipyards today contract vessels based on the traditional Lump Sum Fixed Price (LSFP) contract. Even though the construction of vessels from contract to delivery lasts from a year to longer, there are limited mechanisms available to mitigate for risk during the project evolution, especially in the case of prototype vessels, which are being built by the shipyard for the first time and include much uncertainty with regards to project drawings, detailed material lists and man-hours. Shipbuilding is definitely a large engineering construction project (LECP). Therefore it is logical to analyse how LECPs are contracted and managed in other industries which successfully minimize contract risk and constantly ensure profit in its business. In this paper two new shipbuilding-contracting models are presented and applied in a generic case study of contracting the newbuilding of a prototype vessel. The Cost Plus Incentive Fee (CPIF) and the Cost Plus Fixed Fee (CPFF) contract models are demonstrated as improving the contracting process while yielding positive results for production, both in relation to the core capabilities of the shipyard as well as the sub-contracted activities in vessel production. Likewise a product work breakdown structure PWBS is shown as the model for shipyard business that very well complements the advanced contracting models. Finally a new contract risk analysis method using Monte Carlo simulation is developed to show how to practically analyse and compare the contracting methods in a case study so that shipyard management could choose the contracting model with the least amount of risk.

Key words: *shipbuilding contracts; risk analysis; product work breakdown structure; Monte Carlo simulation.*

1. Introduction

Today most shipyards sign contracts with ship-owners that can be defined as a “Lump Sum Fixed Price” (LSFP) contract [1] in which the total price of the vessel paid by the ship-owner to the shipyard is defined along with milestone payments. However, since many European shipyards are moving away or have moved away from building standard tankers and bulkers to more high value added vessels with greater compensated gross tonnage (CGT) values, it is necessary to analyse and determine new contracting methods which will decrease the risk of shipyards that want to engage in building prototype vessels different and more complex than the standard production program to date.

The problem that many shipyards that are still contracting based on traditional LSFP contracts are that the risk sharing is not fairly distributed among the stakeholders in order to allow for the necessary competitiveness of the shipyard. Modern shipyards need to continue to analyse new methods of contracting which are more in line with a product work breakdown structure (PWBS) [2]. In the oil and gas processing industry, the construction of any type of a "Large Engineering Construction Project" (LECP) has already for some time used more advanced contracting methods between contractors and purchaser as well as sub-contractors and subliferaton, and this practice has successfully lead to profit gains in virtually all projects. Shipyards using traditional contracting methods on the other hand lack the necessary mechanisms to guarantee them earning a profit, which results in constant sustainability and future investments to insure constant advancements in the technology and methodology necessary to be competitive on the world stage [3]. When a contractual process negotiated by a shipyard does not follow modern negotiation methods, the result is often a "contractual disaster" [4]. Shipyards that do not produce large series of vessels but small product mixes need to consider abandoning traditional LFSP contract models and replacing them with newer contract types in order to be viable and survive in the competitive market place.

This leads us to the analysis of the Cost Plus Incentive Fee (CPIF) contract, where the shipyard is guaranteed a minimal profit along with an incentive for a greater profit shared with the owner. An alternative contract is the Cost Plus Fixed Fee (CPFF) contract that is similar to a CPIF contract, with the exception that under a CPFF contract the shipyard is guaranteed a fixed profit with no additional cost incentive [1].

In this paper the authors analysed the three different contract types in a generic case study based on the construction of a prototype vessel such as a factory stern trawler fishing vessel operating in extreme ice conditions. This represents a possible type construction in the future for shipyards since the need to preserve and process fish at sea in extreme Arctic conditions in order to increase the added value of the fishing industry at sea instead of relying on factories on the mainland. The trend is for the advancement of these types of high value added vessels [5]. However, since these vessels must have high autonomy in open seas as well as super ice class conditions, it is necessary for shipyards that have never built these vessels to analyse contracting models which will have both a positive strategic effect for the entire business while enabling minimal risk to both the shipyard and the owner, as well as enticing perspective sub-contractors and subliferation to be competitive in their bids. In order for the European shipbuilding industry to remain competitive it is necessary that the sub-contractors and subliferation also partake in the risk. The risk distribution should be spread out fairly. Otherwise the decline of the shipyard, which is the primary contractor, will lead to the decline of the smaller shipbuilding sub-contractors. The proper and correct implementation of the contracting method will entice a Product work breakdown structure (PWBS) along with lean techniques to be engaged both at the strategic and tactical levels in the industry [6], [7].

Finally, a new contract risk analysis method of the different contract types demonstrates how a generic inquiry for the construction of stern factory trawlers could result in an interesting project for all players in the industry. The owner, the shipyard and the prospective sub-contractors and subliferation as well as classification societies, equipment producers, outfitting and accommodations, engine maker, steel production are all key stakeholders in the shipbuilding industry.

2. Defining contract types

As explained above the three contract types analyzed in this work include LSFP, CPIF and CPFF. Traditional shipyard sales departments estimate a fixed price for a newbuilding construction. Once the contract is signed, there are limited if any mechanisms for price adjustment favorable to the shipyard. This also means that there are no possibilities for the shipyard to increase its profit once the contract is signed. Therefore it is necessary to analyze methods, which allow for realistic and fair price adjustment. Especially since earning profit is the reason for shipyards to operate, and not relying on state subventions as is the case with many shipyards. The input variables in a contracting algorithm include the profit P, the target profit P_T, the contract cost C_C, the actual cost to build the vessel C, and the target cost calculated by the shipyard C_T. In addition there is also a sharing factor "a" between the shipyard and owner. This factor determines the type of contract. Therefore the key equations can be expressed mathematically in equations (1) and (2) as follows [1]:

$$P = P_T + a(C_T - C) \tag{1}$$

$$C_C = C + P \tag{2}$$

2.1 Lump Sum / Fixed Price (LSFP) contract

The obligation for completing the ship is the sole responsibility of the shipyard given of course that the purchaser makes the milestone payments on time and according to schedule. The shipyard needs to include all types of perceivable risk such as unexpected costs that were not inherent in the calculation and estimation of the vessel cost. For instance fluctuations in material costs, and additional man-hours not planned in the contract estimate. At the same time, if the shipyard adds too much risk leeway in its bidding price, this may lead the owner to choose another shipyard with a lower price for the newbuilding instead. The estimation of the vessel cost includes the cost of materials, man-hours, depreciation costs and the profit. Given that the cost of materials stays the same as predicted during contract signing, and the production man-hours remain at the forecasted level, the shipyard could expect to earn a profit. If however, which is frequently the case for many shipyards, the cost of materials and production man-hours exceed the predicted shipyard estimates, then the profit becomes smaller. If the material costs and or production man-hours exceed the shipyard estimation at even higher levels, then the profit translates to a loss, and the shipyard will end up owning money instead of earning. In the LSFP contract the "sharing rate" "a" is always equal to 1. Therefore equation 1 above translates to equation (3) below [1]:

$$P = P_T + (C_T - C) \tag{3}$$

$$C_C = P_T + C_T \tag{4}$$

Likewise, the contract cost Cc is equal to the sum of the target profit P_T and the target cost C_T both estimated by the shipyard sales department as demonstrated in equation (4) above. The situation with this type of a contract is that if the shipyard cost C of building the prototype vessel exceeds the cost estimated by the shipyard sales department C_T, then the actual profit P in equation 3 will be lower than the target profit P_T.

Try to provide good quality figures, as you would wish them to look when published. Do not use embedded vector graphics because of possible side effects. Use raster graphics in a resolution not less than 300 dpi. Try to balance the figure size according to information you are trying to present to reader. Allow a small percentage of figure resizing for the sake of typesetting.

2.2 Cost Plus Incentive Fee (CPIF) contract

The advantages of a CPIF contract are that they make it the shipyard's prerogative to bring the costs to a minimum by enticing efficiency in production and procurement of materials. Therefore, a shipyard, which is building a prototype stern trawler factory vessel with unrestricted voyage for the first time, could engage in this risk. The owner is realistic to the shipyard making a profit and for all costs to be covered. In return, the owner has the opportunity to minimize shipbuilding costs. The contract cost C_C is known upon the completion of the vessel. If the actual cost C is less than the target cost C_T of the vessel, then the sharing rate agreed upon between the owner and the shipyard is between 0 and 1. For instance, if the sharing rate is 50 percent between the shipyard and the owner, then "a" is 0,5. The shipyard is guaranteed a profit P_T that is the target profit given that the shipyard meets certain minimal requirements. Likewise the shipyard has a right to the sharing rate "a". The owner takes over all of the risk if the shipyard meets "performance criteria" such as quality, delivery on time, and safety. There is a "cost performance incentive" for the shipyard if the actual cost is less than the target cost C_T. We go back to equation (1) regarding the profit. If the actual cost is greater than the target cost, then the sharing rate "a" is 0 and the shipyard receives the target profit. This is mathematically explained by equation (5) below.

$$P = P_T \tag{5}$$

If however, the actual cost is less than the target cost, then equation 1 is valid. Additionally, equation 6 mathematically explains the cost related profit. The shipyard is guaranteed a profit P_T and there is a chance for cost related profit P_C is mathematically defined by equation (6) [1]:

$$P_C = a(C_T - C) \tag{6}$$

The total profit received by the shipyard is as equation 1 above.

2.3 Cost Plus Fixed Fee (CPIF) contract

With the Cost Plus Fixed (CPFF) contract, the shipyard is guaranteed a profit from the owner. The actual cost of building the ship has no effect on the profit of the shipyard [8]. In a CPFF contract the owner pays the shipyard a fixed fee (profit). The owner reimburses the shipyard for all costs associated with building of the ship shown in equation (7) below [1]:

$$C_C = P + C \tag{7}$$

The contract cost Cc or the cost of the owner to the shipyard is equal to the profit P which is constant plus the actual cost of building the ship C determined upon delivery. The contract between the owner and the shipyard relates effectively to the delivery of services required in building a ship as opposed to delivering a vessel. Therefore in this contract model the shipyard has the least risk, while the profit negotiated with the owner is certain but usually limited.

3. Stochastic simulation of the different contracts

Since there is much uncertainty in determing contract prices, the authors have decided to apply stochastic simulation as a reliable method of testing different contract types. Based upon previous research in production man-hours where there is much uncertainty, the authors have decided to apply Monte Carlo simulation integrated with the PERT distribution using the @RISK add-on for Excel by Palisades corporation since it allows for readily available inputs of least, most likely and greatest values [7], [9], [10].

3.1 PERT distribution

The Program Evaluation Review Technique (PERT) distribution has similarities to the triangular distribution used in the past except that it is smoother around the ends and allows for realistic extreme values whereas the triangular distribution does not [11], [12]. The authors of this work decided to use the PERT distribution due to its history of more reliability when sampling parameters in a case study, since it maps out realistic industry man-hours and costs. Likewise the benefit in making use of three readily available paramters, minimum, maximum and most likely is practical for defining the distribution in a practical and effective manner [13].

3.2 Monte Carlo Simulation

The Monte Carlo method is used when it is not practical or impossible to compute an exact result with deterministic methods. There is no single Monte Carlo method; instead the term describes a large and widely-used class of approaches [14]. The authors adapted the Monte Carlo method to work with a PERT distribution in order to perform repeated sampling to determine the most likely outcomes in the contract price range adapted for shipbuilding contracts. The four main steps include:

1) Defining inputs within a certain distribution such as PERT.
2) Generating cost inputs randomly from the PERT distribution.
3) Calculations using the PERT distribution.
4) “Aggregating the results” of the individual computations into the final result [14].

The integration of the PERT distribution in the Monte Carlo simulation provides results, which allow shipyard management to make better decisions before choosing a final contract model. Advancement in computers resulted in the development of pseudorandom number generators, which is key to Monte Carlo simulation becuase they are much faster to use than the tables of random numbers which had been previously used for statistical sampling [14].

The advent of personal computers during the 1980s and its continuous improvement and accessibility till today in conjunction with readily available software means that all scientists, engineers and businessmen can find application of Monte Carlo methods.

The Monte Carlo simulation process defines a probability distribution for each contract type cost. Combining the advantages of using the PERT distruibution in conjunction with a Monte Carlo simulation provided in the EXCEL @RISK add-in is the creation of a cumulative distribution function which illustrates the cost distribution in a realistic way. The EXCEL @RISK simulation tool works by picking a random contract cost from each distribution and uses that for the actual cost for the contract type. It does this for every task in the network 1000 times, until a probability distribution of possible outcomes is recorded. In this way Monte Carlo simulation provides a much more comprehensive view of what may happen, and how likely it is to happen [15], [16].

In order to transform classical shipyards to modern and competitive ones, shipyard management needs to make use of tools and methodologies to decrease uncertainties and business risk through making accurate and realistic predictions regarding production and financial outcomes. Consulting with experts from within the shipyard and with outside consultants will result in determining realistic minimum, maximum and most likely values for different scenarios and contract models. Afterwards all three contracting models need to be analyzed. For the purposes of setting an example based on experience from *Capital Contracting Services, Shell Global Solutions International* [1], it is necessary to consider one relevant example used in the contracting phase of Large Engineering Construction Projects (LECPs).

4. Generic case study

The authors made use of the graph with three main contracting methods CPFF, CPIF and LSFP, used for the contracting of construction projects in the oil and gas industry. These graphs predict real world contract cost distributions. The y-axis is the cumulative probability, whereas the x-axis signifies the contract cost with 100 as a mean value (See Figure 1).

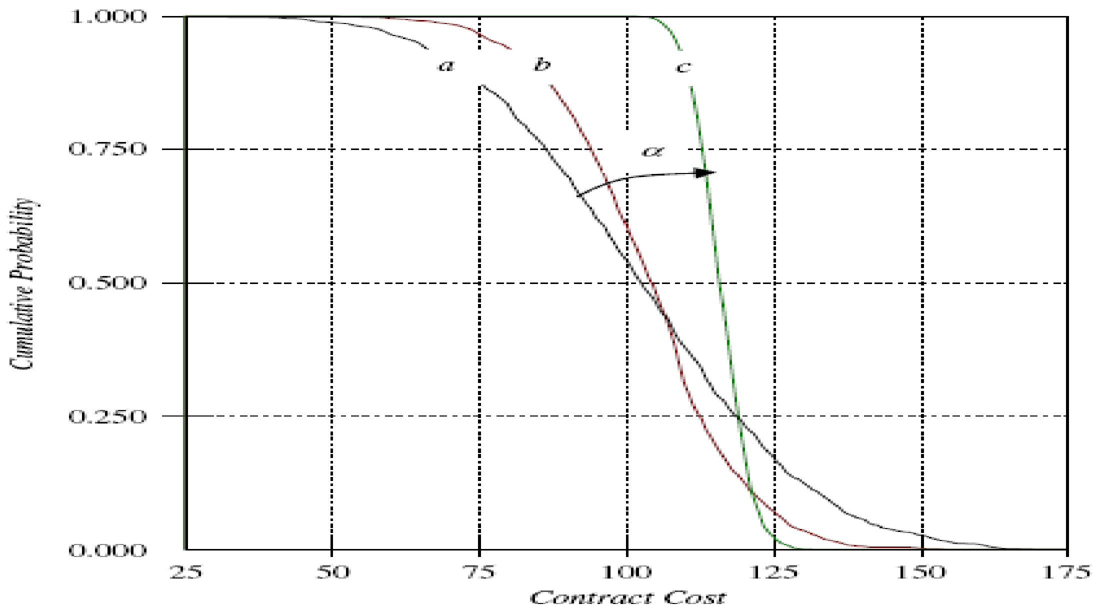

Fig. 1 Contract types: (a) CPFF; (b) CPIF; (c) LSFP [1]

By reading the minimum, maximum and mean values for each curve, Table 1 below was created for each contract type.

Table 1 Berends curves converted to PERT variables

Index	Contract type	X_{min}	X_{mean}	X_{max}
A	CPFF	40	106	165
B	CPIF	56	110	150
C	LSFP with hedging	100	118	130

The "c" curve represents the behaviour of a LSFP with hedging contract which has the least variation; the "b" curve represents a CPIF contract and "a" represents a CPFF contract with the largest minimum to maximum range. The x-axis represents the contract cost with 100 being estimated as the most likely price for the engineering construction project. The y-axis represents the cumulative probability. The type of curves developed represents cumulative descending curves. The area under each of the curves always adds to 1. The authors decided to use this graph as a basis for performing a transformation for shipbuilding contracts since the oil and gas industry has much experience in both theoretical and practical analysis in the behaviour of contract types. Table 2 below is developed using the standard calculations for the theoretical values, and the experimental values from the Monte Carlo simulations using @RISK Palisades Corporation program for Excel [17].

In the hypothetical case study, the sales department of a shipyard estimates the cost of a prototype stern trawler vessel to be roughly 55 million USD. The X_{min}, $X_{most\ likely}$ and X_{max} values are all numerically interpolated from Table 1. The theoretical variances and standard deviations are calculated using standard calculations from [17]. The experimental values are received after performing the simulation using @RISK Palisade's corporation software where the following command in equation (8) is used:

$$=\text{RISKPERT (Lower bound value, Most likely value, Upper bound value)} \quad (8)$$

Summary table for Monte Carlo analysis of a case study interpolated from the Figure 1 curves [17].

Table 2 Numerical interpolation of Table 1 and Monte Carlo simulation

Contract type	X_{min}	$X_{most\ likely}$	X_{max}	S^2 Theor.	S^2 Exper.	s Theor.	s Exper.	μ Theor.	μ Exper.
	USD x 10^6			(USD x 10^6)^2		USD x 10^6			
LSFP non hedging	55	55	55	0,0	0,0	0,0	0	55	55
LSFP with hedging	55	64,9	71,5	7,6	9,16	2,8	3,10	64,34	64,34
CPIF	30,8	60,5	82,5	74,2	98,0	8,6	9,55	59,21	59,82
CPFF	22	58,3	90,8	131,3	169,2	11,5	13,18	57,65	57,96

"X_{min} = lower bound value"

"X_{max} = upper bound value"

"$X_{most\ likely}$ = most likely value"

"$s^2_{Theor.}$ = theoretical variance explained in equation 3 above"

"s_{Theor}. = theoretical standard deviation explained in equation 4 above."

"s^2_{Exper}. = experimental variance received from Monte Carlo simulation"

"s_{Exper} = experimental standard deviation received from Monte Carlo simulation"

"$\mu_{Exper.}$ = experimental mean value obtained from Monte Carlo simulation"

4.1 Monte Carlo Simulation Results

For the LSFP non-hedging curve in the first row of table 2, where there is no possibility for price change, the variances and standard deviations are zero, while the experimental mean is the same as the theoretical mean of 55. This is because there are virtually no methods for changing the price of traditional LSFP contracts. The graphical results of the Monte Carlo simulation for the LSFP non-hedging curve are illustrated in Figure 2 below. The vertical straight line means that the area below the curve is zero. The LSFP curve with no hedging represents traditional lump sum contracting used in traditional shipbuilding contracts. All the risk lies with the shipyard. There is no way to make any price adjustments regardless of the market situation. This contract is very risky for the series production of vessels since just the cost of steel may vary from year to year. Likewise currency fluctuations may also result in negative financial situation for the shipyard, but also for the owner.

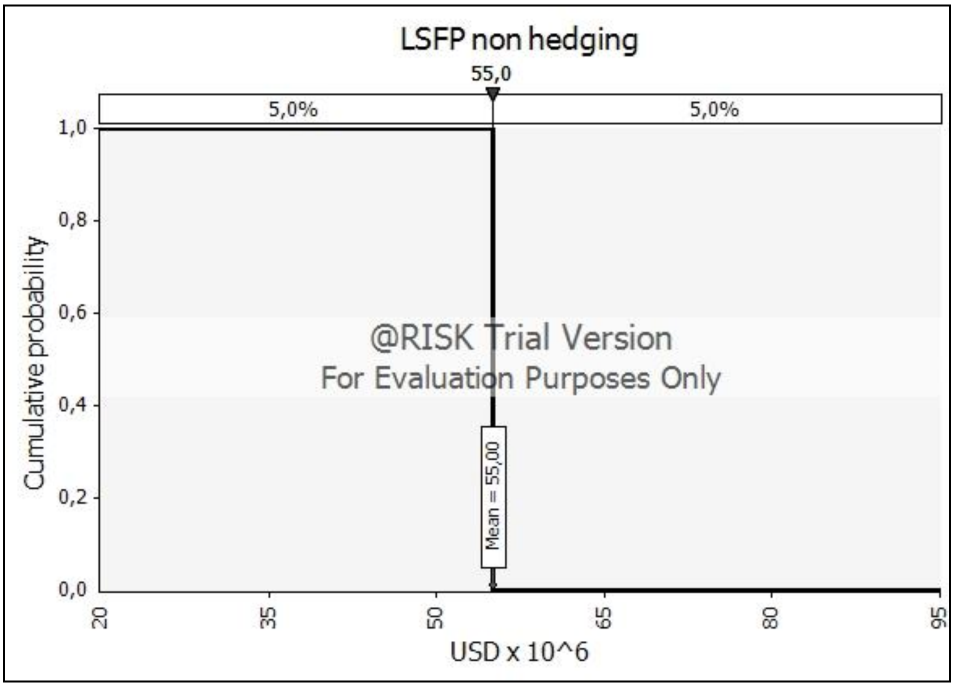

Fig. 2 Lump sum fixed price (LSFP) Curve with no hedging

That is why it is necessary to analyze an LSFP with hedging curve. The experimental mean $\mu_{\text{Exper.}}$ of 64,35 is close to the theoretical mean $\mu_{\text{Theor.}}$ of 64,34. The theoretical variance s^2_{Theor} and experimental variance s^2_{Exper}.are 7,6 and 9,16 respectively, whereas the theoretical standard deviation s_{Theor}. and experimental standard deviation s_{Exper} are 2,8 and 3,1 respectively (See Table 2). Therefore, it is necessary to include hedging in the contract which allows for realistic and fair price adjustment. This leads us to the graphical Monte Carlo simulation results of the LFSP curve with hedging and therefore lesser risk for the shipyard due to the mechanism for adjusting the final price during the construction of the vessel due to market changes in the price of material such as steel (See Figure 3).

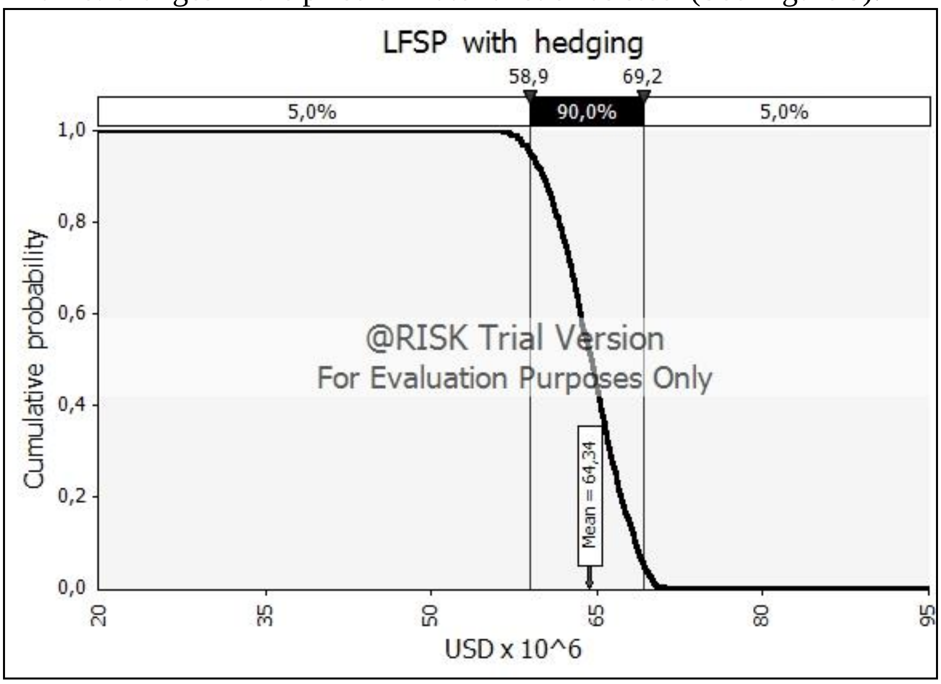

Fig. 3 Lump sum fixed price (LSFP) curve with hedging

In the LFSP curve with hedging, the risk is reduced for the shipyard and also for the owner. For instance, the contract price value which represents the most likely value of 64,34 million USD is a more realistic situation with the ever changing market and its effect on the cost of materials as well as inflation, currency flucatuations, and uncertain project changes which all drive up the cost of building the prototype vessel. The theoretical mean μ_{Theor}, and the experimental mean are both 64.34. The theoretical variance s^2_{Theor} is 7,6 whereas the experimental variance s^2_{Exper} is 9,16. The theoretical standard deviation s_{Theor} is 2,8 while the experimental standard deviation s_{Exper} is 3,1 (See Table 2 and Figure 3).

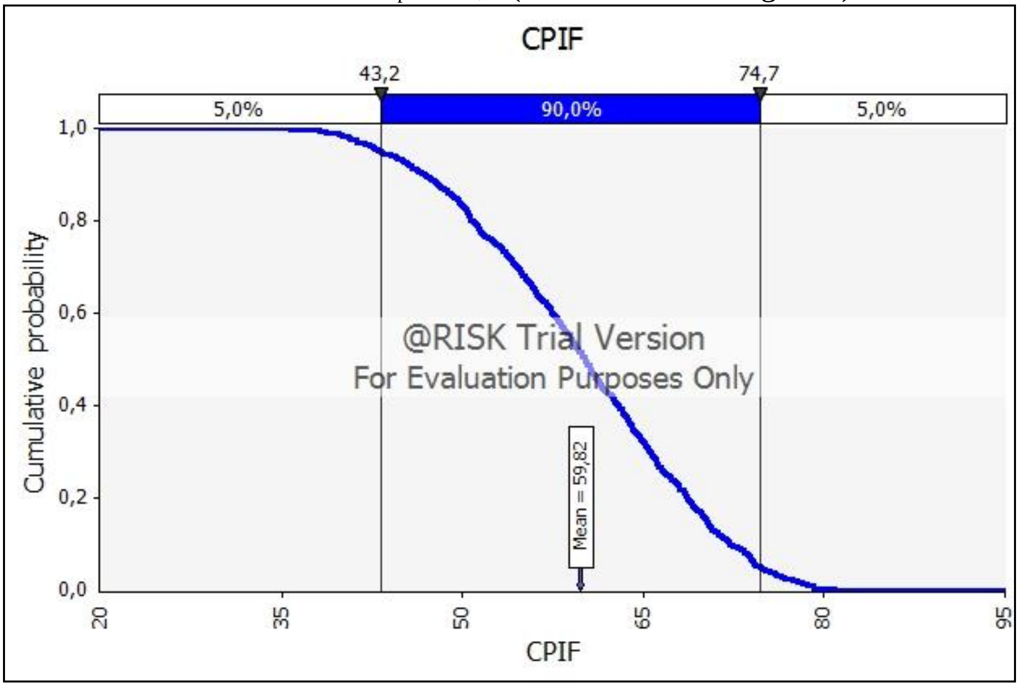

Fig. 4 Cost plus incentive fee (CPIF) curve

For the CPIF curve, the theoretical mean μ_{Theor}, *and* experimental mean μ_{Exper} are very close, 59,21 and 59,82 respectively while there are slightly bigger differences between the theoretical and experimental standard deviations and variances. The theoretical and experimental standard deviations are s_{Theor} 8,6 and s_{Exper} 9,55; and the variances are s^2_{Theor} 74,2 and s^2_{Exper} 98 (See Table 2 and Figure 4). These greater variance and standard deviation values mean that there is a broader array of contract price possibilities than with the LFSP with hedging contract. However the mean value of 59,82 which is lower than the 64,34 value of the LFSP contract with hedging is beneficial for the owner and the shipyard in comparison to the LFSP with hedging contract because it gives more incentive for the shipyard to apply a PWBS system with better control of its man-hours. In this way the shipyard and sub-contractors keep costs to a minimum while simultaneously enabling an increase in their profit sharing.

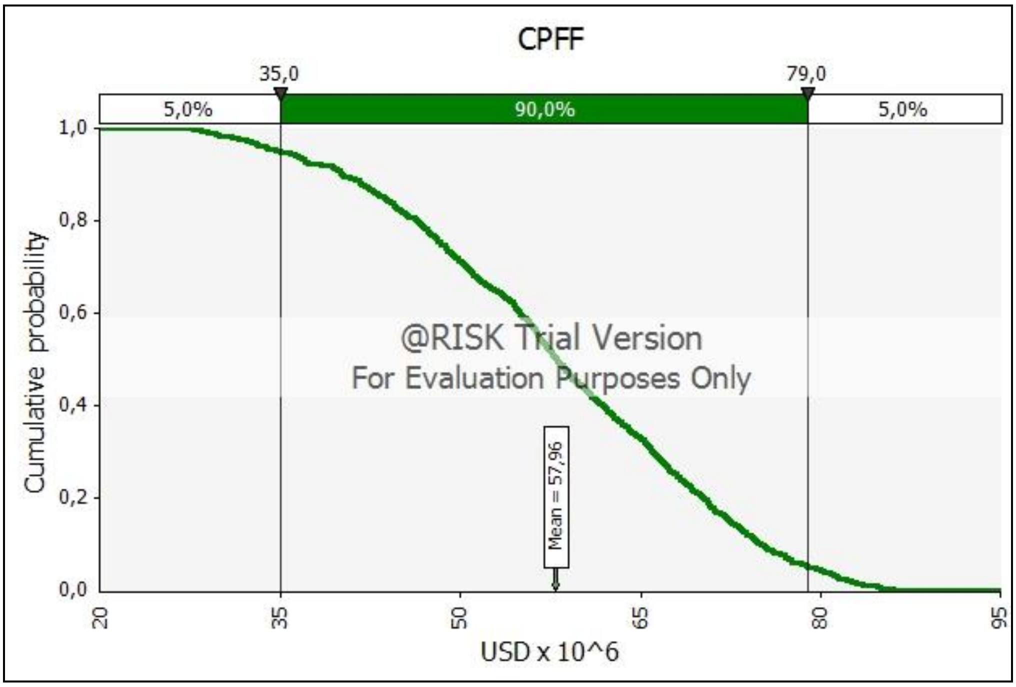

Fig. 5 Cost plus fixed fee (CPFF) curve

For the CPFF curve the theoretical and experimental means are μ_{Theor} 57,65 and 57,96 respectively. The theoretical and experimental standard deviations are s_{Theor} 11,5 and s_{Exper} 13,18, while the theoretical and experimental variances s^2_{Theor} 131,3 and s^2_{Exper} 169,2 (See Table 2 and Figure 5). The span of values for the CPFF curve is even greater than that of the CPIF and LSFP curves. However, the mean value is somewhat smaller than the CPIF value of 59,82. Therefore, when then is less incentive to bring costs down, the price of the vessel will likely be larger. This is less beneficial for the owner, but good for the shipyard that is engaging in a prototype shipbuilding project.

4.2 Monte Carlo simulation results

The LSFP curve without hedging is the model that Croatian shipyards have been using till 2008. Since it does not allow price adjustment in the volatile market, it is no longer recommended in shipbuilding projects or any other Large Engineering Construction Projects. LSFP with hedging allows for price adjustment. It is ideal for shipyards that are contracting vessels, which they have much experience in building, and allows for adjustment of contract price based on possible fluctuations in the price of steel or other main components such as main machinery engine. Likewise the fluctuations in the exchange rate of major world currencies such as the US dollar or the Euro can also be taken into account in this type of a contract. CPIF is ideal for shipyards trying to contract special vessels, which are not built in large series, and in which there is a learning curve. CPFF is similar to CPIF, except that the profit is always fixed. This model is ideal for the contracting of special prototype vessels which shipyards have little or no experience in building. Therefore the risk for the shipyard is minimized while guaranteeing a minimal profit.

5. Application to a shipbuilding contracting problem

Considering the situation of a shipyard contracting a prototype vessel which has never before designed or built, it is necessary to determine which contract type is optimal both for the shipyard and the purchaser. Shipyards are facing decreasing order books. The case of a shipyard, which has built special naval vessels in the past, but in the recent past has mainly built passenger ferries wishes to move into the area of contracting sophisticated factory trawlers. The estimations for material (steel, main-engine, outfitting equipment) and production (man-hours) and overhead costs are made. Standard type vessels such as tankers, container ships, and even RO-RO vessels are already saturated by many yards in the Far East with whom it is simply hard to compete due to the smaller prices. However shipyards not producing large series of vessels need to compete for the building of state of the art vessels for continually emerging markets such as sophisticated factory trawlers and other special mission type vessels for offshore purposes such as servicing wind farms which are not ordered in large series and require the use of modern contracting methods in order to minimize and balance the risk between the stakeholders while delivering the vessel to the owner that meet owner and classification society requirements at a competitive price [18], [19], [20].

6. Conclusions

The LSFP contract without hedging should generally not be used anymore by shipyards because they are inherently risky. This was the method of contracting in Croatian shipyards till 2008. The LSFP contract with hedging is the latest trend. However, it is the optimal contract only in instances where the vessel is one that is very well understood by the engineers, workers and management of the shipyard. Prototype vessels, which were never built in Croatian shipyards, should not be contracted with this model, because the risk would be too high. The CPIF contract allows for a large range of contract price adjustment. The shipyard profit is also adjustable. For projects where the shipyard is subcontracting work, this contract model is optimal as is the case for accomodation fabrication and outfitting since the subcontractor has the incentive to keep costs minimal and is rewarded with a greater profit. The CPFF contract is similar to the CPIF contract, except that the profit for the shipyard is minimized. However, this contract is optimal for the contracting of complicated prototype vessels, where a shipyard needs to minimize risk, while ensuring a minimal profit. In this way the shipyard maintains survivability during a recession in the world shipbuilding market.

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Nomenclature

LSFP	- lump sum fixed price
LECP	- large engineering construction project
CPIF	- cost plus incentive fee
CPFF	- cost plus fixed fee
CGT	- compensated gross tonnage
P	- profit
P_T	- target profit
P_C	- cost related profit
C	- actual cost to build the vessel
C_T	- target cost to build the vessel
C_C	- contract cost
a	- sharing factor

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