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Magne Emhjellen, Kjetil Emhjellen and Petter Osmundsen

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Magne Emhjellen**, Kjetil Emhjellen***, and Petter Osmundsen****

***Stavanger University College*
**** Telemark University College*
***** Stavanger University College / Foundation for Research in Economics and Bus. Adm.*

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[**] Magne Emhjellen, Stavanger University College, Department of Business Administration, Po Box 2557 Ullandhaug, 4091 Stavanger, Norway Tel: (47) 51 83 15 82, Fax: (47) 51 83 15 50, Email: Magne.Emhjellen@oks.his.no
[***] Kjetil Emhjellen, Telemark University College, Department of Engineering, Po Box 203, N-3901 Porsgrunn, Norway Tel: (47) 35575201, Fax: (47) 35575204, Email: Kjetil.Emhjellen@hit.no
[****] Petter Osmundsen, Stavanger University College, Section of Petroleum Economics, Po Box 2557 Ullandhaug, 4091 Stavanger, Norway. Tel: (47) 51 83 15 68, Fax: (47) 51 83 17 50, Email: Petter.Osmundsen@tn.his.no, Internet: http://www.snf.no/Ansatt/Osmundsen.htm

Abstract

Recently, a Norwegian government report on the cost overruns of projects in the North Sea was presented (NOU 1999:11). It concluded that there was a 25% increase in development costs from project sanction (POD, Plan for Operation and Development) to last CCE (Capital Cost Estimate) for the 11 oil field projects investigated. Many reasons like unclear project assumptions in early phase, optimistic interpolation of previous project assumptions, too optimistic estimates, and underestimation of uncertainty were given as reasons for overruns. In this article we highlight the possibility that the cost overruns are not necessarily all due to the reasons given, but also to an error in the estimation and reporting of the capital expenditure cost (CAPEX). Usually the CAPEX is given by a single cost figure, with some indication of its probability distribution. The oil companies report, and are required to do so by government authorities, the estimated 50/50 (median) cost estimate instead of the estimated expected value cost estimate. We demonstrate how the practice of using a 50/50 (median) CAPEX estimate for the 11 projects when the cost uncertainty distributions are asymmetric, may explain at least part of the "overruns". Hence, we advocate changing the practise of using 50/50 cost estimates instead of expected value cost estimates for project management and decision purposes.

Keywords: Investment Decision, Expected Value, Construction Cost Estimation, Capital Expenditures (CAPEX), Probability Distribution of CAPEX.

Jel.no.: G31, L72, M21

1. Introduction

The development cost and time for completion of projects on the Norwegian Continental Shelf have been substantially reduced over the last decade, but not as much as expected. This is confirmed by the government report NOU 1999:11 which describes cost overruns in the amount of 25 billion NOK (approx. 3 billion USD) for projects approved in the period from 1994 to 1998. Optimistic evaluations, strategic bidding, and too many simultaneous developments are some explanations for the cost overruns.

According to McMillan (1992), cost estimation is particularly difficult in the construction industry, often leading to considerable cost overruns. The explanations are that there often is large uncertainty and that the uniqueness of the projects limits the learning process. One might expect that cost overruns have the same probability as completing the project below the cost estimate. However, observations clearly indicate an overrepresentation of cost overruns.[1]

The cost overruns normally refer to a project's capital expenditures (CAPEX) which is the development cost of the project. The CAPEX is developed through a cost estimate, very often by a company's cost estimation department. Usually the CAPEX is given by a single cost estimate, with some indication of its probability distribution for this cost estimate. In this article we demonstrate how the project management practice of using a 50/50 (median) CAPEX in the 11 field projects investigated in the 1999 NOU report leads to underestimation of the expected CAPEX cost, given the assumption that the cost distributions for each cost element are asymmetric. The use of the 50/50 CAPEX estimate instead of the expected value may explain at least part of the observed "cost overruns" from POD to last CCE.

2. Cost Estimation Failures on The Norwegian Shelf

In the beginning of the 1990s, the Norwegian petroleum industry experienced a cost level that did not justify new offshore development projects. To reduce development time and costs drastically on the Norwegian shelf, economic and technical task forces were appointed, with members from the oil companies, the suppliers and government. This process, known as NORSOK, was inspired by the cost reduction initiative CRINE on the UK shelf. A consensus

[1] An asymmetric cost structure may be due to two types of selection bias: 1) project selection; it is typically the projects with the most optimistic internal cost estimates that are being pursued by the investing firm, and 2) tender selection; competition sees to that tenders with pessimistic and realistic cost estimates are ruled out.

was reached in the Norwegian petroleum industry to implement a number of organisational and contractual changes.

Much attention has been devoted to reducing the lead time. Deep water offshore development projects are extremely capital intensive, and getting the field on stream at an early stage may be decisive for a positive project appraisal (net present value analyses). To reduce the development time, contract award (and to some extent fabrication) has started before detailed engineering was completed. This has led to a considerable increase in estimation risk. For a number of extraction facilities there have been considerable amounts of reengineering and refabrication, causing delays and cost overruns. In some cases this has been due to updated information about reservoir characteristics and a wish to implement new technology. In other cases the initial engineering and planning were simply inadequate.

Previously, oil companies (the licence groups, represented by the operators) coordinated deliveries from contractors that were specialised within, respectively, project management, engineering, module fabrication, at-shore/inshore hook-up or marine operations. Today, the Norwegian offshore development market is dominated by 3 to 4 major entities marketing themselves as capable of carrying out total enterprise contracts and/or projects from concept development to offshore installation and start up. Hence, the project management tasks which previously had to be carried out by a project team managed by the client, have after 1994 been carried out by the major offshore contractors, regulated by EPCI-contracts (Engineering, Procurement, Construction, Installation). The large size of the contracts, and the new coordination tasks that were to be performed, implied a considerable increase of risk for the turnkey suppliers. In the previous fabrication contracts, founded on cost-plus principles, most of the risk was borne by the oil companies. In the EPCI-contracts, however, an even split of cost overruns and savings, relative to a target sum was introduced. There was an upper limit to the cost overruns to be borne by the contractor, but this cap was substantial compared to the contractor's financial strength. Thus, in a situation of a considerable increase in risk, a higher fraction of the risk is now borne by the contractors.

The performance of the new contractual and organisational solutions in Norwegian offshore development projects was evaluated by a government study (Government Report NOU

1999:11).[2] For the new type of development projects, implemented after 1994, the study reports aggregate cost overruns exceeding 3 billion dollars. Still, development costs are estimated to have fallen; but not to the extent of the over-optimistic expectations. As a result, the main contractors have experienced financial problems. Moreover, clients have been forced to pay in excess of their contractual obligations in order to secure delivery of the contract object when contractor's financial stability is jeopardised. A poor technical definition and a resulting under-estimation of scope has also caused schedule delays and subsequent losses to the oil companies that they were unable to recover through liquidated damages paid by contractors.

Experience gained by the Norwegian oil industry indicates that there should be more focus on developing better technical specifications prior to the award of EPCI contracts; planning time has been less than optimal. Furthermore, incentive contracts need to be curtailed to the financial capacity of the supplier. The choice of design time - which influences the amount of risk - must be seen in conjunction with the risk sharing arrangements.[3] Also, the need for improved cost estimation has clearly been demonstrated[4]. The 50/50 (median) CAPEX cost estimation procedure has been - and is - used by e.g. the two major Norwegian oil companies, Statoil and Norsk Hydro. It is also this type of cost estimate that all companies on the Norwegian shelf are to report to the Norwegian Ministry of Oil and Energy and the Norwegian Oil Directorate.

3. Uncertainty Distributions of Costs

A cost estimate for a project is a prediction or forecast of the total cost of carrying out the project, which can be illustrated by a distribution curve. Illustration A shows an uncertainty distribution that is symmetric from the mode, median, and expected value.

[2] The cost overruns are also analysed from a contractual and organizational perspective, see Osmundsen (2000).
[3] For a discussion of risk sharing in the petroleum sector, see Osmundsen (1999) and Olsen and Osmundsen (2000).
[4] Benchmarking could be one way for an oil company to improve it's cost estimation practice. See Emhjellen (1998) and Emhjellen (1997) for a discussion on how to carry out such a benchmarking.

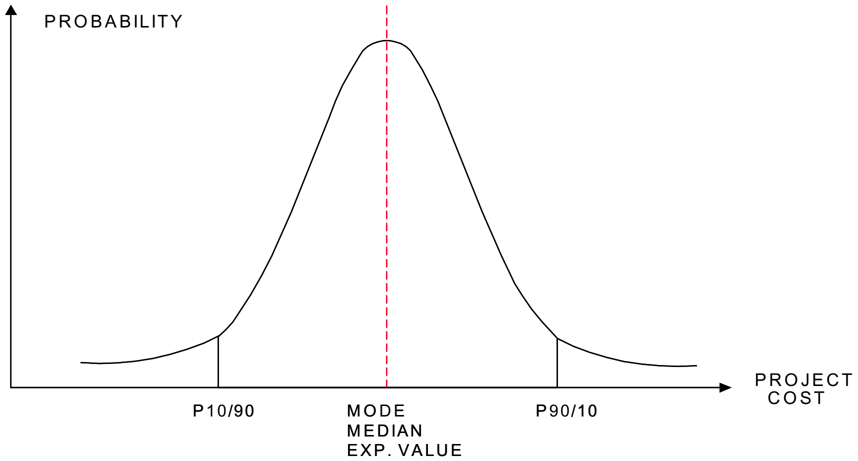

Illustration A: CAPEX symmetric uncertainty distribution

The P10/90 (P10) project cost value is defined as the cost level with 90% probability of overrun, and 10% probability to underrun. Conversely, the P90/10 (P90) value is the value with 10% probability to overrun, and 90% probability to underrun. The median, also called 50/50 estimate (P50/50), is the value with equal probability (50 %) that the cost will be higher or lower. In a symmetric distribution, the mode, median, and expected values coincide. This is not the case for an asymmetric distribution.

Illustration B depicts an asymmetric distribution of project cost, which is positively skewed. In such a distribution, the mode, median and expected value are different and, respectively, in increasing size (Wonnacott, 1990).

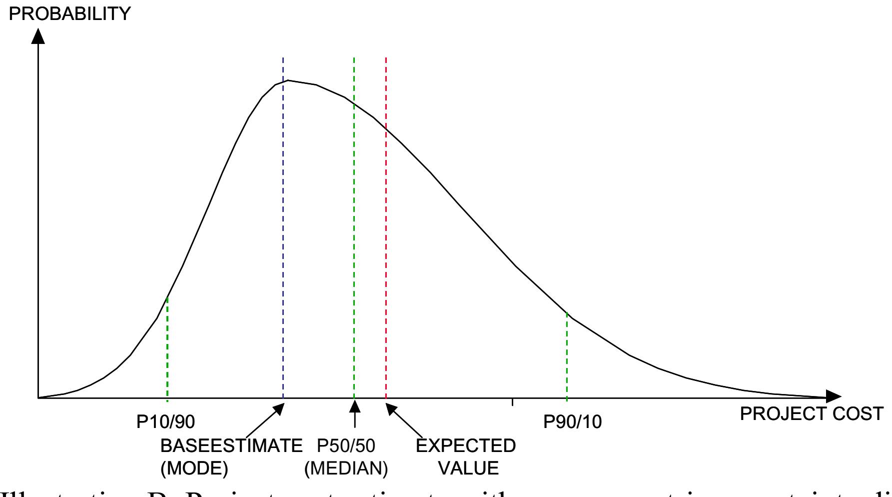

Illustration B: Project cost estimate with an asymmetric uncertainty distribution (positively skewed)

The statistical figures of median, mode, and expected value represent a special value in a skewed distribution (Wonnacott, 1990; Humphrey, 1991; Austeng and Hugsted, 1993). As explained, the median (P 50/50) is the value that has the same probability (50%) of overrun as underrun. In a lottery of all possible project cost values, the mode is the single value that has the highest probability to be drawn. Thus, the modal value is the cost that reflects the top point of the distribution curve. The expected value - also referred to as a weighted average - is the sum of all outcome times the respective probabilities.

There are several reasons to change the CAPEX reporting from 50/50 to expected value as discussed in Emhjellen et. al. (2001). The three major ones are summarized below:

1. Expected value is the anticipated total cost of a project. Consequently, the expected value should be the reported investment cost figure (CAPEX) for a project.
2. Income, and other costs/expenditures, e.g., OPEX, are reported as expected values and used in net present value calculations. For the sake of consistent comparisons and project value determination, all cash flows including CAPEX should be expected values.
3. The expected value is easier to correctly use statistically when developing and handeling an estimate. For instance, expected values for several cost elements can be summarized where the aggregate sum also becomes the expected value for the sum of the elements (often incorrectly used with 50/50 values being summarized). The difference between 50/50 and expected value may be small for one cost element, but the difference may be large when aggregating 50/50 values expecting the sum to be the total 50/50 value). In addition, standard deviation is measured from the expected value, not the median (50/50 value).

4. Current Practice and Reported Cost Overruns

The oil industry and many other industries adhere to a common practice of reporting a CAPEX that is the estimated 50/50 (median) instead of the expected value. The 50/50 CAPEX estimate is usually reported together with a) the base estimate (which is the sum of all defined cost elements, i.e. sum of all cost elements' modal values), and b) the contingency (usually defined as "The amount of money in a cost estimate to cover the difference between the 50/50-Estimate and the Base Estimate.") (Emhjellen, et al 2001)

In the report (NOU 1999:11) the issue of 50/50 cost estimate versus the expected value cost estimate is not mentioned. However, the 50/50 cost estimate at time of POD is the basis for the reported cost overruns. In addition the uncertainty distribution given in the report is drawn as symmetric. Our belief is that even if the uncertainty distribution for the total portfolio of projects were close to being symmetric, the uncertainty distribution of the individual cost elements comprising the developments are not.

In order to show the difference with respect to the assumption on the uncertainty distribution of individual cost elements, we use the 50/50 estimate for the 11 offshore projects reported in NOU 1999:11 at time of POD, and in section 5 assume that the uncertainty distributions associated with these 50/50 CAPEX estimates are asymmetric. The 11 projects are: Balder, Gullfaks South, Jotun, Njord, Norne, Oseberg South, Oseberg East, Troll oil and gass province (TOGP), Varg, Visund and Asgard. Illustration C reflects the 50/50 CAPEX estimates at time of POD, while illustration D reflects the 50/50 CAPEX estimates at last CCE.

Cost group	Balder POD 50/50 Est	Gullf. S. POD 50/50 Est	Jotun POD 50/50 Est	Njord POD 50/50 Est	Norne POD 50/50 Est	Oseb.S. POD 50/50 Est	Oseb.E. POD 50/50 Est	TOGP POD 50/50 Est	Varg POD 50/50 Est	Visund POD 50/50 Est	Asgard POD 50/50 Est	SUM POD 50/50 Est.
Plattforms	2188	0	4139	2918	4392	2982	1595	3813	1994	3070	9994	37085
Production wells	1217	1918	1135	993	1253	2366	1016	6924	553	2526	7162	27063
"Management"	373	1236	508	710	1034	712	247	791	168	627	3996	10402
Underwater inst.	1226	1688	416	653	1367	400	0	5357	158	1205	3693	16163
Marine operat.	0	595	0	209	509	578	180	367	25	74	2327	4864
Modifications	0	1419	0	0	0	472	118	300	0	109	0	2418
Contingency	0	0	0	0	66	0	0	0	0	0	1219	1285
Completion	0	0	0	77	0	145	64	0	37	90	136	549
Storage ships	0	0	0	750	0	0	0	0	0	0	0	750
Pipeline export	0	0	0	0	0	392	267	697	0	150	0	1506
SUM	5004	6856	6198	6310	8621	8047	3487	18249	2935	7851	28527	102085

Illustration C: CAPEX estimation for 11 North Sea Project at time of POD (all values in million Norwegian kroner, MNOK)

From illustration C and D we observe that the aggregate cost for the 11 projects have increased from 102 billion NOK (Illustration C) to 127 billion NOK (illustration D). In other words; at last capital control estimate (CCE) the total CAPEX cost for all projects had increased by more than 25 billion NOK, an increase of nearly 25 per cent.

	Balder	Gullf. S.	Jotun	Njord	Norne	Oseb.S.	Oseb.E.	TOGP	Varg	Visund	Asgard	SUM
	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE	L. CCE
Cost group	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est	50/50 Est.
Plattforms	3683	0	4717	3143	4352	3158	1936	5072	2055	3994	11558	43668
Production wells	1692	3849	1149	2059	1903	2770	1334	7582	835	3518	10417	37108
"Management"	1234	1280	646	716	1030	711	297	1553	300	1598	5248	14613
Underwater inst.	1108	1673	567	825	1380	475	0	5817	173	1338	5312	18668
Marine operat.	120	607	0	119	543	536	267	318	133	121	2764	5528
Modifications	0	1590	0	0	0	506	88	250	0	154	0	2588
Contingency	140	0	125	0	66	0	8	0	0	122	1469	1930
Completion	108	0	0	236	0	145	175	0	140	391	199	1394
Storage ships	0	0	0	663	0	0	0	0	0	0	0	663
Pipeline export	0	0	0	0	0	449	192	179	0	134	0	954
SUM	8085	8999	7204	7761	9274	8750	4297	20771	3636	11370	36967	127114

Illustration D: CAPEX estimation for 11 North Sea Project at last CCE (all values in million Norwegian kroner, MNOK)

Our hypothesis is that at least part of this "cost overrun" can be explained by the practise of using a 50/50 estimate from an asymmetric uncertainty distribution where the expected value is greater than the 50/50 estimate (Emhjellen et al, 2001). Consequently, we believe the higher estimate given by the expected value should be used.

5. Simulation of Cost Based on Positively Skewed Uncertainty Distributions

The cost estimation practice of using a 50/50 estimate instead of the expected value may be based on an incorrect interpretation of the Central Limit Theorem. The Central Limit Theorem, first stated by Liapounov in 1901(DeGroot, 1986), gives us the opportunity under certain conditions to approximate the uncertainty distributions of a sum of independent variables by a normal distribution. Thus, in the aggregated normal distribution curve the expected value and the 50/50 (median) value will be the same, as shown in the symmetric curve in Illustration A. However, this is true only for a symmetric curve.

The conditions for the Central Limit Theorem to apply can be summarized in the following conditions (Austeng and Hugsted, 1993):

1. The number of the N independent variables are large.
2. The uncertain variables $X_1, X_2, \ldots, X_n$ are independent but there are no restriction on the type of distribution each uncertain variable may have.
3. No single variable X_n should dominate the sum $\left(\sum_{i=1}^{n} X_i\right)$.

Under the assumption that the three conditions are satisfied, the aggregated total cost of a project (CAPEX) may be approximated by a normal distribution. The cost estimates may then be calculated with the use of the Central Limit Theorem.

However, the majority of the single cost elements that makes up a CAPEX are positively skewed, which makes it neccesary to aggregate the single cost elements expected value estimate (not 50/50 estimate) in order to obtain an estimate for the expected total CAPEX cost. Typically, the distribution's spread and skewness are also underestimated. Our hyphothesis that most projects have a positively skewed CAPEX are above explained by selection biases of projects and tenders. We also believe that the three conditions for the Central Limit Theorem to hold usually are not met with respect to project cost, e.g. due to a limited number of very large projects.

Humphrey (1991) has also made this point: " In practice, estimates and uncertainties will not follow a normal distribution or even be symmetrical about the mean”. When we do not have normal distributions, the general approach is to employ simulations using the Monte Carlo technique.

Based on the CAPEX cost development of the 11 North Sea Projects we want to illustrate the possible errors of the cost estimation practice and give a likely explanation for at least part of this cost overrun by assuming only asymmetric uncertainty distributions for each cost group (see illustrations C and D).

Assuming a skewed beta-curve with expected values for each cost group at time of POD that were 10% higher than the median value, and a standard deviation of 25% of median, where minimum value was one - 1 - standard deviation below median, and maximum value three - 3 - standard deviations above median, we undertake Monte Carlo simulations (using @-Risk; Palisade, 1998). Illustration E shows the new expected values.

Cost group	Balder New est. Expected	Gullf. S. New est. Expected	Jotun New est. Expected	Njord New est. Expected	Norne New est. Expected	Oseb.S. New est. Expected	Oseb.E. New est. Expected	TOGP New est. Expected	Varg New est. Expected	Visund New est. Expected	Asgard New est. Expected	SUM New est. Expected
Plattforms	2406,8	0	4552,9	3209,8	4831,2	3280,2	1754,5	4194,3	2193,4	3377	10993,4	40793,5
Production wells	1338,7	2109,8	1248,5	1092,3	1378,3	2602,6	1117,6	7616,4	608,3	2778,6	7878,2	29769,3
"Management"	410,3	1359,6	558,8	781	1137,4	783,2	271,7	870,1	184,8	689,7	4395,6	11442,2
Underwater inst.	1348,6	1856,8	457,6	718,3	1503,7	440	0	5892,7	173,8	1325,5	4062,3	17779,3
Marine operat.	0	654,5	0	229,9	559,9	635,8	198	403,7	27,5	81,4	2559,7	5350,4
Modifications	0	1560,9	0	0	0	519,2	129,8	330	0	119,9	0	2659,8
Contingency	0	0	0	0	72,6	0	0	0	0	0	1340,9	1413,5
Completion	0	0	0	84,7	0	159,5	70,4	0	40,7	99	149,6	603,9
Storage ships	0	0	0	825	0	0	0	0	0	0	0	825
Pipeline export	0	0	0	0	0	431,2	293,7	766,7	0	165	0	1656,6
SUM	5504,4	7541,6	6817,8	6941	9483,1	8851,7	3835,7	20073,9	3228,5	8636,1	31379,7	112294

Illustration E: Results from Monte Carlo CAPEX Simulation (uncorrelated, 2000 iterations).

The assumed higher expected value of 10% for each cost group may be added both on project and project portfolio level, aggregating to an increase in the CAPEX cost estimate from 102 billion NOK to 112 billion NOK. The assumption of asymmetric uncertainty distribution, where expected value is 10% higher than the 50/50 estimate, therefore explains only part of the observed cost increase of 25% to 127 billion NOK. Part of this cost increase however, occurred as a result of optimizing the project (thus imposing variation orders) as new information where available (mainly regarding the reservoir - thus demanding a different extraction capacity of the installation - and implementation of new technology). However, this puts focus directly on our point that the uncertainty distribution of the CAPEX estimate is likely to be skewed and that estimation of the expected value is necessary. The difficulty of including the asymmetric nature of costs when new information is obtained is obvious, but nonetheless a necessary effort in order to achieve an estimate that reflects the “true expected value” as close as possible. For instance, expected technology development, expected inflations, expected new regulations, anticipated new taxes, etc. should all be included in the project management process when assessing and estimating expected costs. Also, if the estimation procedure within the project management system is correct, the cost overruns in one project should be offset by lower than expected costs in others so that the total aggregate cost is close to the expected total cost estimated at time of POD.

The statistics from our simulation (2000 iterations) are a minimum CAPEX estimate of 100448 billion NOK, a Mode of 108506, a median (50/50) of 112180, an expected of 112294 and a maximum of 126360. Observe the closeness of the 50/50 estimate with the expected value estimate. This is the result of the Central Limit Theorem. However, the 50/50 estimate for the aggregate portfolio of projects is not equal to the sum of the 50/50 estimates of each cost group for each individual project(which is much lower). It is the sum of the expected values of each cost group that becomes “equal” to the 50/50 and expected total CAPEX estimates.

With correlated cost elements we would obtain similar results to that obtained in Emhjellen et al (2001). The expected value would be the same as in the uncorrelated simulation, the 50/50 and mode value would be slightly smaller and the distribution would have a larger spread where the P10 (P10/90) and P90 (P90/10) values would be further away from the expected value. Thus, correlated elements will influence on the spread of the distribution and to a smaller degree on the skewness of the distribution.

6. Conclusions

In our opinion the various cost groups of the development projects are likely to have asymmetric uncertainty distributions which are positively skewed where expected value is greater than the 50/50 estimate. Given asymmetric uncertainty distributions for the cost groups it is the expected value estimate that must be added to give the total cost estimate and not the 50/50 cost estimate. Given the use of the 50/50 cost estimate at time of POD it is likely that all the reported cost overruns in NOU 1999:11 are not cost overruns only, but also partly due to a system error in the estimation of the expected project cost. The reasons given above make it important to use the expected value cost estimate in project management.

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