Framework to Implement Six Sigma Methodology to Oil and Gas Drilling Budget Estimation

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Abstract

Budget estimation is a crucial element in planning for Oil and Gas drilling systems. Drilling involves many uncertainties such as material, labor or overhead cost, inflation, oil price…etc. Oil and Gas companies mainly rely on deterministic approach to estimate the drilling cost. This approach is highly subjective and does not account for uncertainties. This paper suggests a framework to incorporate Six Sigma methodology to estimate the budget in order to minimize the prediction errors. The model uses Newsvendor model to obtain the optimal value for the cost and then utilize the expert opinion through Bayesian inference, and the test it using Monte Carlo Simulation. The model starts by updating the distribution for the drilling cost and later updates it using expert opinion. The expert is provided with drilling and well information to help in capturing their belief about the cost distribution for a particular well. Then a final distribution is obtained as an end result of the Six Sigma Model.

Keywords
Six Sigma, Newsvendor Model, DMAIC Methodology

1. Introduction

In most oil and gas companies, drilling-budget estimation relies on deterministic approach, in which the forecast method does not incorporate uncertainties and risk factors surrounding all well engineering phases. The deterministic approach is assumed to be "certain" under the assumed scenarios (although some of its input parameters may be quite uncertain). The use of deterministic analysis in cost estimation is done by using historical cost and duration data and expert's opinion to subjectively estimate the well cost and duration. This approach has two inherent difficulties: it is heavily subjective, and the impact of external factors is not adequately considered. The limitations of deterministic practice have necessitated the need for a predication model which is capable of representing reality and yet leads to a "better" prediction. In the journey to construct the model, the following methodology is adopted (Figure 1).

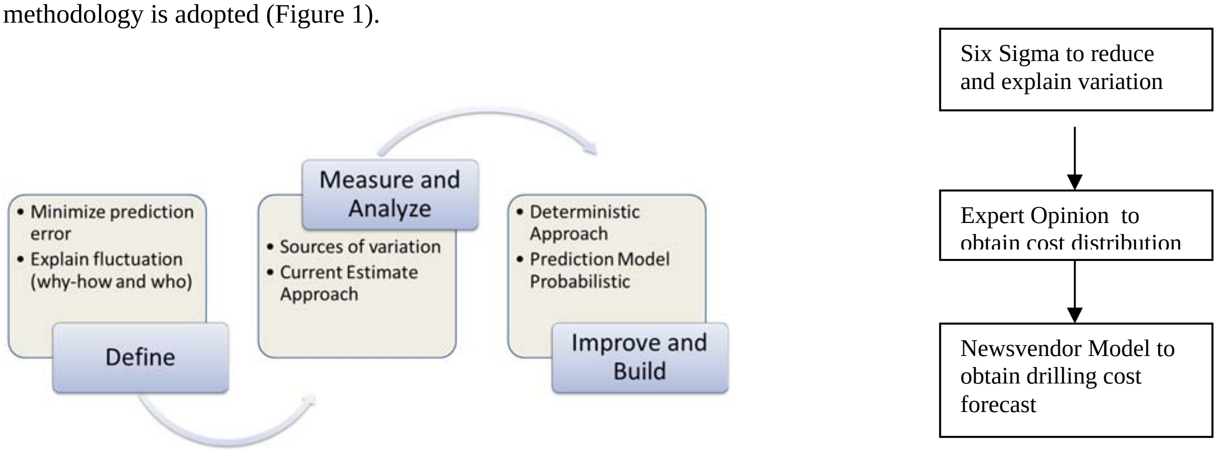

Figure 1: Suggested Framework to incorporate Six Sigma (DMAIB)

Many oil and gas companies utilize expert opinion, historical data, and a deterministic prediction system. Therefore, a systematic model that incorporates these elements with uncertainty is essential. Six Sigma is a systematic tool that reduces deviation from target throughout DMAIC approach. Since the deviation from actual cost or duration may result on an unclear budgeting system and thus we consider them as defect. The limitation of the deterministic model makes the need for a better prediction model essential. One main cause of this deviation from target is variation due to controlled and uncontrolled factors in the drilling process. The framework suggests that clear objectives and problem definitions are crucial. Our main objective is to reduce variation first by eliminating the causes and then getting expert opinion about the cost distribution. After that, we implement Newsvendor model to get the optimal forecast. At this stage iterations are suggested to obtain relevant data that suits the project objectives. The objective is to minimize the prediction error for cost and budget given available historical. Moreover, it is essential to measure the current status of prediction system used by the company because of two reasons: (1) Utilize the available data in an effective way in the deterministic estimation approach and (2) Learn from the deterministic approach to build a probabilistic model that fits any company need. The main goal then is to build a model that is able to utilize the historical data and combine it with probabilistic approach to give three-point estimates for both cost and duration for subsequent years.

Six sigma has been implemented successfully in various fields to reduce the number of defects and to bring the quality level in the organization to its expected. Many examples of Six Sigma applications was found in the literature. However, few of these applications have introduced Six Sigma to Oil and Gas field. Douglas and William (2008) reviewed the development of six sigma from historical perspective also they discussed the phases and the steps to be implemented, moreover the required statistical methods used within six sigma. Roger G et al (2008) proposed base definition of six sigma and the initial theory based on the grounded. Hongbo(2008) explained the background of six sigma and that it was implemented first time by Motorola company to reduce the number of defects into 3.4 defect per million opportunity also he gave summary about the methodology of six sigma and what are DMAIC and DFSS processes .B. Tjahjono et al(2010) they identified the latest trends ,various approaches, tools and techniques and the benefits of combining six sigma with other concepts .Also Young and Frank (2006) reviewed and examined the evolution, benefits and the challenging of applying six sigma into the real field also they identified the most important key factors that will lead into a successful implementation of six sigma into the projects. Jeroen and Joran (2012) conceived of DMAIC as problem solving tool and analyzed it from that side of view also they found that DMIAC process is applicable to the empirical problems but not to the ill structured problem.

Satya (2009) developed six sigma program in a network company in USA and implemented model consists of six steps :strategic analysis, establish high level cross functional team, identifying overall improvement tools, performing high level process mapping, developing detailed plan and to form low level improvement teams. Another study was done by Obaidullah(2005) and he studied the implementation of six sigma in UK organizations and found that six sigma has been adopted in both manufacturing and service organizations in UK and it require an average of four to nine month to complete full six sigma project ,also the percentage of the employees who have been involved in these projects was 1-20%. Jiju Antony et al (2006) discussed the importance of six sigma in the service industry and the benefits will be gained after the implementation of six sigma projects, and they found that majority of service organizations in UK have been engaged in six sigma and the average level of the companies was around 2.8 sigma with 98000 DPMO. Furthermore six sigma also can be applied in the field of pharmaceutical industries and it contain huge opportunity to implement the DMAIC process .Karl (2008) applied a stability test to diagnose quality level of the materials and reagents ,and he found that two parameters are linked with pharmaceutical and diagnostics stability testing are :real time stability monitoring and accelerated stability testing processes then he applied the full DMAIC process and he conclude that the process capability must be considered equally as important as the science behind the testing. Recentrly, González Falcón *et. al.*(2012) applied six sigma methodology to improve energy efficiency in a distillation unit of a naphtha reforming plant and they reproduced the model of energy consumption with an expected savings of 150,000€/year by optimizing the distillation process of a naphtha reforming unit through identifying the causes of variation in 14 critical inputs.

This paper illustrates how to incorporate Six Sigma in budget estimation for Oil and Gas field. The model is applying various Six Sigma tools and incorporate with other known models in supply chain such as Newsvendor model , Bayesian inference, and Monte Carlo Simulation. The paper first discusses the model structure then presents a case study in which we apply the model.

2. Six Sigma Prediction Model

The main objective is to find an optimal value for each well-type that will minimize the deviations from actual value. This optimal value depends on historical data, underestimation and overestimation penalties, and other factors. The best model for this scenario is “Newsvendor” model.

2.1 Factors to consider

To be practical, uncertainties cannot be predicted by a single scenario. However, decision maker should make an informed judgment and hope for the best. Therefore, the estimation model should incorporate as many factors as possible that help shape these uncertainties; the historical data can give an indication about the most likely value for both cost and duration. The historical data can give the following information: (1) Actual cost and duration , (2) Learning experience, (3) Sources of variation within year or between years, and how much other factors such as tools or drilling methodology change contribute to the variation in the data. Relying solely on historical data to predict for future might mislead the prediction model. Thus, having expert’s belief or opinion about what should be actual cost and duration is essential. The challenge is how to help expert set a prior distribution for actual cost. The learning experience is modeled using Wright (1936) model.

Expert opinion about actual cost and duration will benefit the model and make it more practical. The reason is that the historical data may have an average accuracy level. This “average” accuracy level could be a result of missing data, unclear method for collecting data, or that data are gathered from various departments in oil and gas companies which may have unclear measurement system. To help experts, the model extracted relevant information (as summarized previously). These relevant pieces of information include: (1) Trends in the data, (2) Sources of variation, and (3) Learning experience. The end result of the expert opinion is a probability density function that gets updated using the historical data. However, this is not rigid and experts can still have an influence in the end result distribution as will come in the example provided in case-study section. Moreover, the expert state of knowledge can be explained by a member of the beta family distribution. It is entirely possible that the state of knowledge will not be adequately described by a beta distribution, but the flexibility that beta family distribution has makes it “effectively” capture expert opinion.

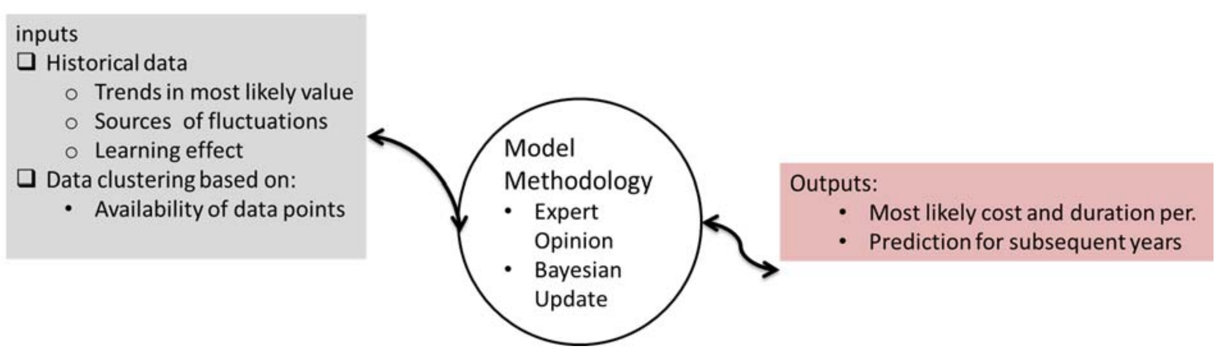

Figure 2 : Six Sigma Model Inputs and Outputs

The stochastic approach will incorporate historical data, and expert opinion through three risk analysis techniques: Bayes theory to update the state of knowledge of expert, Newsvendor model to obtain the optimal estimate, and Monte Carlo simulation to test the estimation model. The model should be dynamic and can be updated whenever new information about cost and duration is available. Experts’ opinion should utilize well-cards which have relevant information to extract their belief about cost and duration. After that, a set of Bayesian inference is applied to obtain the predicted distribution for the subsequent years. Then optimal solution with marginal error can be provided. The model has its limitations and error is expected since we are dealing with uncertainties. The model entirely relies on the data provided. If the data is not reliable then expert opinion should be another source to balance the error in the end result of the model.

3. Case Study

The model was applied for estimating a cost for drilling a well in Oman. The historical data for years 2008-2012 were tested. The data provided contain the actual cost and duration, various rigs operating in the well. The model should predict the future cost and duration for the subsequent year. To help decision maker (i.e. the budget estimator) a well card that summarizes the sources of variation in both cost and duration was provided (Table1). For each well analyzed, the decision maker was given the optimal forecast using historical data for years 2008-2012.For instance, for any particular well the variation is within the year itself which means that it is internal within the well not due to factors that may change on yearly bases like inflation, rigs, drilling technique. The drilling team is has a learning effect when learning exponent is negative which may reduce the total cost. The well card mentioned in table 1 has the variations details and details are fed to the expert so that s/he can update her/his belief about the actual cost.

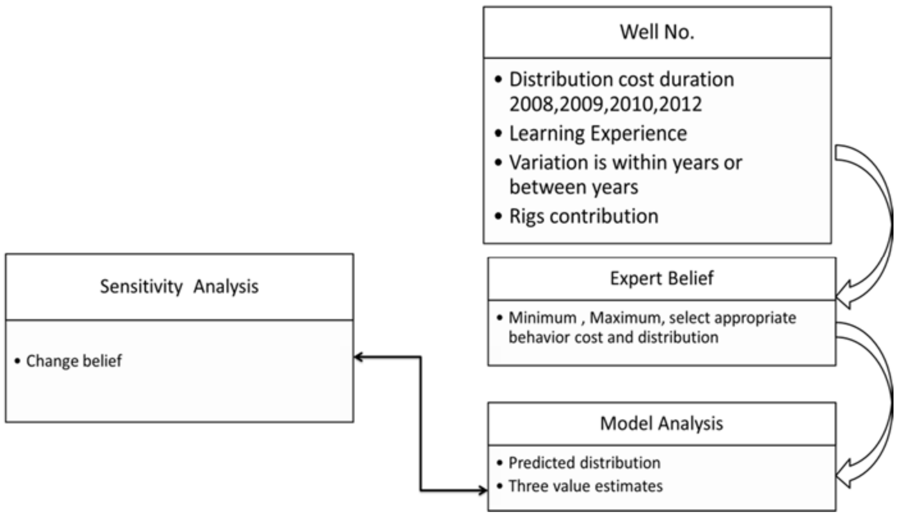

Figure 3: Case Study for an Oil well in Oman*

Table 1: Well Results Card obtained using Newsvendor Model three factors Rig, Month, and Year

Well type #	**Optimal Forecast ($) 2008**	**Optimal Forecast ($) 2009**	**Optimal Forecast ($) 2010**	**Optimal Forecast ($) 2011**	**Optimal Forecast ($) 2012**	**Learning Exponent**	**Anova Results for Rig.**	**Anova Results for Month**	**Anova Results for Year**
1	-	-	-	2850458	1548903.445	-0.2962	Significant	Not Significant	Not Significant
2	-	1937220	1870199.1	-	-	-0.1066	Significant	Not Significant	Not Significant
3	-	1867292	-	1497595	-	-0.2685	Significant	Not Significant	Not Significant
4	-	-	-	2971332	1670983.47	-0.478	Significant	Not Significant	Significant
5	-	-	-	1745818	-	0	Significant	Not Significant	Significant
6	-	-	2009770.11	1714164	5596799.25	0.7961	Not Significant	Not Significant	Significant
7	-	-	-	-	3133914.21	0.1995	Not Significant	Not Significant	Significant
8	-	-	4607831.41	-	-	0	Not Significant	Not Significant	Not Significant
9	-	-	1726114.55	1366895	-	-0.3729	Significant	Not Significant	Not Significant
10	-	-	397086	-	-	0	Significant	Not Significant	Not Significant
11	8010249.56	-	-	-	-	0	Significant	Significant	Not Significant
12	-	5507049	2412125	-	-	-0.6055	Significant	Not Significant	Not Significant
13	2547146	-	-	-	-	0	Significant	Not Significant	Not Significant

14	2812980.2	-	-	-	-	-0.515	Significant	Not Significant	Not Significant
15	-	4227072	-	-	-	-0.6268	Significant	Not Significant	Not Significant
16	9650972.77	-	-	-	-	0	Significant	Not Significant	Not Significant
17	2956670.11	-	-	-	-	0	No Enough Data	Not Significant	Not Significant
18	-	-	10328178.38	-	-	0	Significant	Not Significant	Not Significant
19	4376082.12	-	-	-	-	0	Significant	Not Significant	Not Significant
20	-	-	4844343.48	-	-	0	Significant	Not Significant	Not Significant
21	-	5102415	-	-	-	0	Significant	Not Significant	Not Significant
22	-	-	-	-	3708192.5	0	Not Significant	Not Significant	Not Significant
23	6697741	-	3935167.57	-	-	-0.7672	Not Significant	Not Significant	Significant
24	3167668	3525374	2683946.04	-	-	-0.0177	Significant	Significant	Significant
25	-	-	2416497.385	-	-	0.6923	Not Significant	Not Significant	Not Significant
26	-	-	-	2489061	2676637.84	-0.002	Not Significant	Not Significant	Not Significant
27	847952.36	-	-	-	-	-0.0871	Not Significant	No Enough Data	Not Significant
28	-	-	-	-	1293057.75	-0.391	Not Significant	Not Significant	Not Significant
29	794899	-	1227090	-	-	0.0364	Not Significant	Not Significant	Not Significant
30	1001489	-	-	-	-	-0.3675	Not Significant	No Enough Data	Not Significant
31	-	1435797	-	-	-	0	Not Significant	Not Significant	Not Significant
32	3907205	-	-	-	-	_ _	Not Significant	Not Significant	Not Significant
33	-	-	4452648.44	3618634	-	-0.1823	Not Significant	Not Significant	Significant
34	-	-	-	2879690.5	-	-0.2775	Significant	Significant	Not Significant
35	-	-	-	-	3038538.43	0	Significant	Significant	Not Significant
36	-	-	-	3745015.5	-	-0.755	Significant	No Enough Data	Not Significant
37	-	-	2885329.1	-	-	0	Not Significant	Not Significant	No Enough Data
38	-	-	-	2904283	-	0	Not Significant	Not Significant	Not Significant
39	3949301	-	-	-	-	0	No Enough Data	Not Significant	Not Significant
40	2235215.36	2758616	3647311.62	-	-	0.1384	Not Significant	Not Significant	Significant
41	2233935.5	-	-	-	-	0.0227	Not Significant	Not Significant	Not Significant
42	2887132	2464011	2166126.26	2223804	2025876.245	-0.1577	Not Significant	Not Significant	Not Significant
43	-	-	-	3664725	-	0	Not Significant	Not Significant	No enough data
44	-	-	3070373.13	-	-	0	Not Significant	Not Significant	Not Significant
45	-	-	4182583.485	4255901	-	0.085	Not Significant	Not Significant	Not Significant
46	-	1126565	1273019.73	-	-	0.0493	Not Significant	Not Significant	No Enough Data
47	-	-	579034.85	-	-	0	Not Significant	Not Significant	No enough data

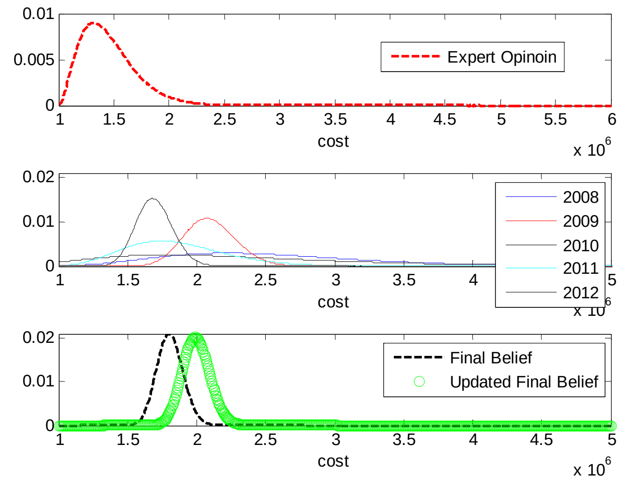

Figure 4: Expert opinion update about the predicted cost for year 2013

The most challenging part in the model is extracting expert opinion. Some ways can be tested or validated through drilling team: (1) Using a set of questions to build a probability distribution about cost and duration for every well type, (2) Letting the expert state the minimum, maximum and most likely or center of the data point, or (3) Providing different probability distribution of beta family given the expert minimum and maximum for particular well type. The third method could be more convenient, but other ways might emerge as development of the estimation model goes forward. Consider the expert opinion about the cost distribution in the well in figure 7. Obviously the expert(s) thinks that the actual cost will be more toward less values i.e. less than 2 million. Then after observing data of 2008-2012, getting the posterior distribution using Bayes theory, the cost distribution (the third bottom distribution) changes accordingly and centers towards values between 1.8-2.0 million. Note that the variance is lowered once the expert observed the data. Also the model is dynamic i.e. it can update itself once the expert receives new information where the final cost distribution centers around 2 million (o green line).

4. Conclusion

We propose a model that incorporate Six Sigma with Bayesian inference and Newsvendor model to build a stochastic prediction model for oil and gas drilling cost estimation. Typically, oil and gas companies rely on expert opinion and deterministic approach which has its limitations. One major limitation is that it does not incorporate uncertainties which surround the drilling process. In addition it is subjective and leads to over or under estimation. The end result of the framework is to incorporate expert opinion, historical data, and uncertainties to produce an optimal forecast using Newsvendor model once the cost distribution is obtained from expert belief.

References

Anbari, F. T, Six Sigma method and its applications in project management. *Proceedings of the Project Management Institute Annual Seminars & Symposium*, 2002.

Asmita S.Joshi, Six Sigma implementation using DMAIC approach, Sandip Institute of Technology and Research Centre, Nashik.

B. Tjahjono and P. Ball, V.I. Vitanov, C. Scorzafave, J. Nogueira, J. Calleja, M. Minguet, L. Narasimha, A. Rivas, A. Srivastava, S. Srivastava and A. Yadav, Six Sigma: a literature review, *International Journal of Lean Six Sigma*, Vol. 1 No. 3, pp. 216-233, 2010.

Douglas C. Montgomery and William H.Woodall, An Overview of Six Sigma, *International Statistical Review 76*, 329–346,2008.

Eric C. Anderson, 20 October 1999, Monte Carlo Methods and Importance Sampling, *Lecture Notes for Stat 578C Statistical Genetics*, 1999.

Hongbo Wang, A Review of Six Sigma Approach: Methodology, Implementation and Future Research, *978-1-4244-2108-4/08 IEEE*, 2008.

Jeroen deMast n, JoranLokkerbol, An analysis of the Six Sigma DMAIC method from the perspective of problem solving, *International Journal of Production Economics*, 139, pp. 604–614, 2012.

Jiju Antony, Frenie Jiju ,Maneesh Kumar, Byung Rae Cho, Six sigma in service organizations Benefits, challenges and difficulties, common myths, empirical observations and success Factors, *IJQRM 24,*(18 pages),2006.

Jonny and Jessika Christyanti, Improving the Quality of Asbestos Roofing at PT BBI Using Six Sigma Methodology, *International Congress on Interdisciplinary Business and Social Science*, 306 – 312,2012.

Karl De Vore, A six-sigma approach to stability testing, *Journal of Pharmaceutical and Biomedical Analysis 47,* pp. 413–421, 2008.

M. Sokovic, D. Pavletic, S. Fakin, Application of Six Sigma methodology for process design, *Journal of Materials Processing Technology,* 162–163, pp. 777–783, 2005.

Obaidullah Hakeem Khan Kundi, A Study of Six Sigma Implementation and Critical Success Factors, *Pakistan's 9th International Convention on Quality Improvement*, 2005.

Pande, P.S., Neuman, R.P. and Cavanagh, R.R. *The Six Sigma way: How GE, Motorola, and Other Top Companies are Honing Their Performance*, McGraw-Hill, NY, 2000.

Roger G. Schroeder , Kevin Linderman , Charles Liedtke , Adrian S. Choo, Six Sigma: Definition and underlying theory, *Journal of Operations Management*, 26, pp. 536–554, 2008.

R. González Falcón , D. Velázquez Alonso , L.M. GallegoFernández, Luis Pérez-Lombard, Improving energy efficiency in a naphtha reforming plant using Six Sigma methodology, *Fuel Processing Technology 103*, pp. 110–116, 2012.

Satya S.Charavorty, Six Sigma programs: An implementation model, *International Journal of Production Economics*, 119, 2009.

SCHWEITZER, M. E. AND G. P. CACHON, Decision Bias in the Newsvendor Problem with a Known Demand Distribution: Experimental Evidence," *Management Science*, Vol. 46, 3, pp. 404-420, 2000.

Suslick, S &Schiozer, D, 'Risk analysis applied to petroleum exploration and production: an overview', *Journal of Petroleum Science and Engineering, vol.*44, no.1-2, pp. 1-9, 2002.

Tushar N. Desai and Dr. R. L. Shrivastava, Six Sigma – A New Direction to Quality and Productivity Management, *Proceedings of the World Congress on Engineering and Computer Science*, 2008.

Wu. J., J. Li, S. Wang and T.C.E. Cheng, Mean-variance analysis of the newsvendor model with stockout cost Omega, 37, no. 3, pp. 724-730, 2009.

Young Hoon Kwak, Frank T. Anbari, Benefits, obstacles, and future of six sigma approach, *Technovation,* 26, pp. 708–715, 2006.

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Biography

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