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From Averages to Reserves: Probabilistic Contingency and Schedule-Buffer Estimation for Highway Change Orders Using Reference-Class Evidence from Egypt

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Abstract

Reports of change-order impact usually give mean cost and schedule growth, but a project owner must set a reserve, not an average. This paper uses recorded before-and-after cost and duration data for 50 Egyptian highway, bridge, and urban-axis projects (original value EGP 381.0 billion) to estimate reserves directly from the empirical distribution of outcomes, following a reference-class approach. Cost growth was right-skewed (skewness 1.65; Shapiro–Wilk $p < .001$), so percentile and bootstrap methods were used. The median project-level growth was 22.5%, the 80th percentile 27.1% (bootstrap 95% CI 25.0–33.3%), and the 90th percentile 33.3%; a flat 25% reserve would have covered 72% of projects. At programme level, bootstrap resampling gave a 95th-percentile growth of 25.5%, so a single project-level P80 reserve would over-provision the portfolio by roughly EGP 12 billion relative to the observed EGP 90.8 billion. Schedule delay was highly discrete (94% of projects delayed by 2–4 months) and scaled with original duration (delay = 0.71 + 0.129 × duration, $R^2 = 0.67$), whereas percentage delay declined with project duration (Spearman $\rho = -0.30$, $p = .033$). Cost and schedule growth were coupled with an elasticity of 0.38 ($R^2 = 0.31$). The data show signs of rounding, which limits precision. The results indicate that reserves should be set from distribution percentiles and from a fixed-plus-proportional schedule model rather than from mean percentages.

Keywords: contingency; reference class forecasting; change orders; schedule buffer; bootstrap; highway projects; Egypt

1. Introduction

Change orders are a recognised driver of cost and schedule growth in highway delivery (Anastasopoulos et al., 2010; Shrestha & Maharjan, 2018; Shrestha et al., 2022). A companion study by the same authors [citation to be added upon submission/acceptance] characterised the mean magnitude of change-order impact in this Egyptian dataset and tested its association with project status, type, size, and change category. That work answers a descriptive question: how large is the impact on average, and what is it related to?

The question addressed here is different and prospective: given a new project of this kind, what contingency and schedule buffer should be held, and with what confidence? Mean growth is a poor basis for that decision. A reserve equal to the mean is exceeded by roughly half of projects, and the distribution of growth is typically

skewed, so the upper percentiles that matter for budgeting differ materially from the mean. Reference class forecasting offers a way to base estimates on the observed outcomes of comparable past projects rather than on bottom-up estimates that tend to be optimistic (Flyvbjerg, 2006, 2008; Flyvbjerg et al., 2002).

This paper therefore treats the 50 projects as a reference class and addresses four questions. (1) What are the percentile reserves, with uncertainty, for project-level cost and schedule growth? (2) How does the required reserve change when projects are pooled into a programme? (3) How is schedule delay structured, and is a percentage buffer an appropriate form for it? (4) How strongly are cost and schedule growth coupled when expressed as ratios? To our knowledge, no previous study offers distribution-based reserve estimates for the Egyptian national road programme.

2. Background

Studies of change orders in Egypt and the wider region have mostly surveyed practitioners on causes, with owner-driven scope change, design omissions, and unclear contract terms ranked highly (Ezeldin & El Sarag, 2018; Albasyouni & Ashraf, 2022; Khalifa & Mahamid, 2019). Register-based quantification comes mainly from United States highway agencies, where change-order growth of roughly 5–7% has been reported for large Texas projects and cost and schedule growth were positively correlated (Shrestha & Maharjan, 2018), with earlier work modelling the cost impact of change orders on roadwork (Serag et al., 2010; Bordat et al., 2004). Change orders also disrupt unchanged work, so schedule effects need not be proportional to the added scope (Moselhi et al., 1991; Hanna et al., 2002; Assaf & Al-Hejji, 2006). Project change management frameworks stress early evaluation of changes (Ibbs et al., 2001). Across large public works, cost estimates are systematically biased downward, which motivated the use of reference classes (Flyvbjerg et al., 2002; Flyvbjerg, 2008).

Two gaps follow. First, the literature reports means and correlations far more often than percentiles with confidence intervals, which is what a reserve decision requires. Second, schedule growth is almost always expressed as a percentage of planned duration, which implicitly assumes delay is proportional to duration. Whether that assumption holds for change-order delay has received little direct testing.

3. Data and Methods

3.1 Data

The dataset contains 50 projects under Egypt's national roads and bridges programme (32 completed, 18 ongoing). For each project, the original and revised contract cost (EGP billion) and original and revised duration (months) were recorded, with a short description of the change orders. Original cost ranges from EGP 2.5 to 40 billion and original duration from 8 to 40 months. Cost growth is (cost after − cost before)/cost before, and schedule growth is (duration after − duration before)/duration before; absolute delay is the difference in months. Values were transcribed from tabulated project records and cross-checked against the reported cost-increase percentages. The full table is given in Appendix A. [Authors: state the exact source, issuing body, and date of the records here.]

3.2 Analysis

Normality was assessed with Shapiro–Wilk tests and skewness. Percentiles (P50, P80, P90, P95) were computed empirically. Uncertainty was quantified by the nonparametric bootstrap with 10,000 resamples of projects (seed 42) and percentile intervals (Efron & Tibshirani, 1993). Coverage of flat reserves was computed as the share of projects with growth at or below a given value. For programme-level growth, projects were resampled with replacement to size 50 and the ratio of total added cost to total original cost computed in each draw; this assumes projects are exchangeable and independent, an assumption discussed in Section 5. For schedule, absolute delay was regressed on original duration, and percentage delay on the reciprocal of original duration, which is the form implied if delay has a fixed component. Spearman correlations were used for rank associations; size and duration groups were compared with one-way ANOVA and the Kruskal–Wallis test. Cost–schedule coupling was estimated as the slope of a log–log regression of the duration ratio on the cost ratio. Analyses used Python (pandas, SciPy, NumPy).

4. Results

4.1 Distribution of growth

Cost growth had a mean of 24.48% (SD 6.65%), a median of 22.54%, and skewness of 1.65; normality was rejected ($W = 0.846$, $p < .001$). Schedule growth had a mean of 17.54% (SD 4.23%), skewness of 0.67, and $W = 0.931$ ($p = .006$). Because the distributions are not normal, mean-plus-standard-deviation reserves are not appropriate, and percentiles are used. Of the 50 cost-growth values, 10 are exactly 20%, and 8 are exactly 25%; of the 50 delays, 49 are even numbers of months. We return to this clustering in the limitations.

4.2 Project-level reserves

Measure	P50	P80	P90	P95	Mean (95% CI)
Cost growth (%)	22.54	27.05	33.33	37.50	24.48 (22.76–26.42)
Schedule growth (%)	16.67	20.00	22.50	25.00	17.54 (16.40–18.75)
P80 bootstrap 95% CI	—	Cost 25.00–33.33; Schedule 20.00–22.22	—	—	—

Table 1. Empirical percentiles of project-level growth and bootstrap intervals (n = 50).

The 80th percentile of cost growth is 27.1%, but its bootstrap interval is wide (25.0–33.3%), reflecting the thin upper tail with 50 observations. Table 2 shows the coverage of flat reserves: a 20% reserve would have been sufficient for only 36% of projects, 25% for 72%, 30% for 86%, and 35% for 92%. A reserve set at the mean (24.5%) covers only 56% of projects, leaving 44% under-reserved; the jump from 36% to 72% between 20% and 25% reflects the clustering of values at exactly 20% and 25%.

Flat reserve (% of original cost)	20	25	30	35
Projects covered (%)	36	72	86	92

Table 2. Share of projects whose cost growth is at or below a flat reserve.

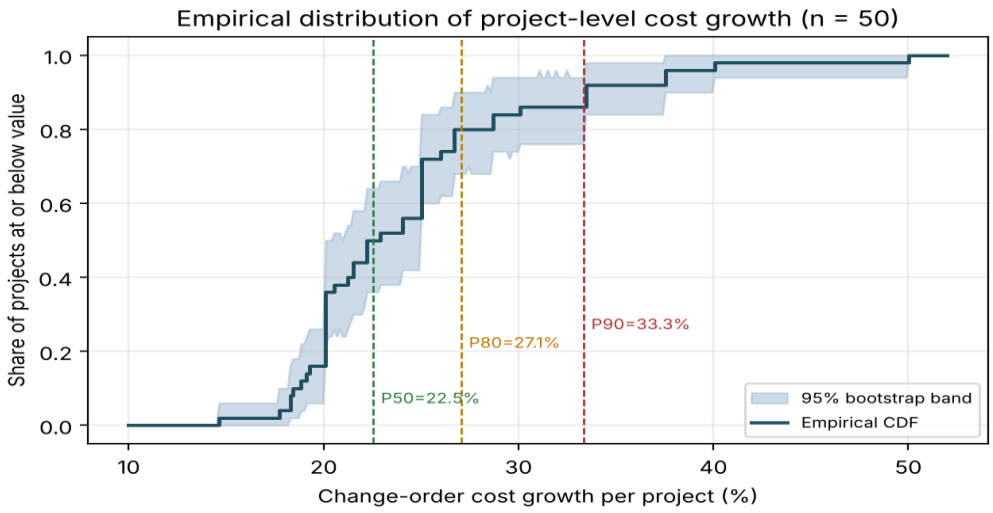

Figure 1. Empirical distribution of project-level cost growth with percentile markers and 95% bootstrap band.

4.3 Programme-level pooling

Observed total growth across the 50 projects was EGP 90.8 billion on EGP 381.0 billion, or 23.83%. In the bootstrap, programme-level growth had a median of about 24% and a 5th–95th percentile range of about 22.3–

25.5% (values vary slightly by the random seed), far narrower than the project-level spread (Figure 2). Applying the project-level P80 of 27.05% to every project would imply a reserve of EGP 103.1 billion, about EGP 12.3 billion (13.5%) above the observed growth, whereas a programme-level P95 of 25.5% corresponds to EGP 97.2 billion. Reserves can therefore be held at programme level at a lower rate than the sum of project-level reserves, provided project outcomes are not strongly correlated.

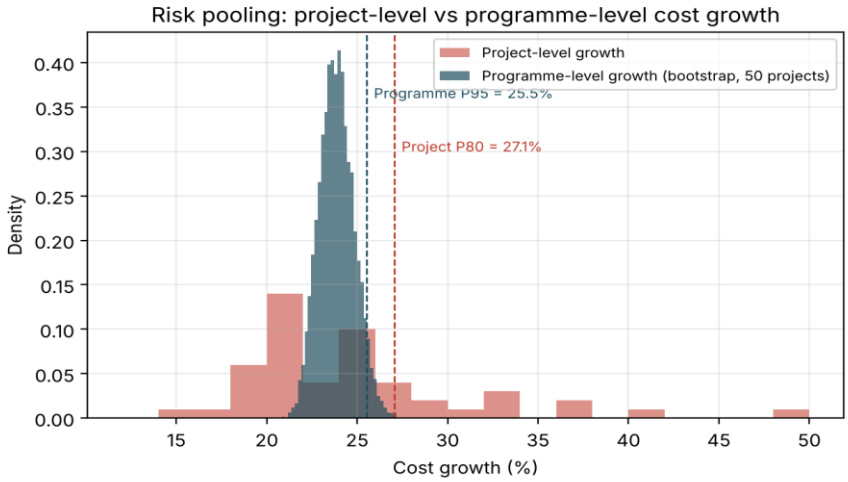

Figure 2. Project-level versus bootstrapped programme-level cost growth.

4.4 Structure of schedule delay

Delays were concentrated at a few values: 2 months in 28 projects, 3 months in one, 4 months in 18, and 6 months in three. The mean absolute delay was 2.98 months (median 2). Absolute delay rose with original duration (Pearson r = 0.82, p < .001); the fitted relation was delay = 0.71 + 0.129 × D0 months (R^2 = 0.67, p < .001), implying a fixed component of about 0.7 months plus roughly 13% of duration. Consequently, percentage delay falls as duration rises: the model predicts 18.9% for a 12-month project, 15.9% for 24 months, and 14.9% for 36 months. Percentage delay was negatively rank-correlated with original duration (ρ = −0.30, p = .033) and with original cost (ρ = −0.32, p = .025), and regression on 1/D0 gave pct = 13.6 + 60.3/D0 (R^2 = 0.11, p = .018). By size tertile, mean percentage delay was 20.0% (small), 15.3% (medium), and 17.0% (large) (ANOVA F(2,47) = 6.87, p = .002; Kruskal–Wallis H = 11.94, p = .003), while mean absolute delay was 2.3, 2.4, and 4.4 months (F = 39.8, p < .001). Cost-growth percentage was unrelated to original cost (ρ = −0.06, p = .70).

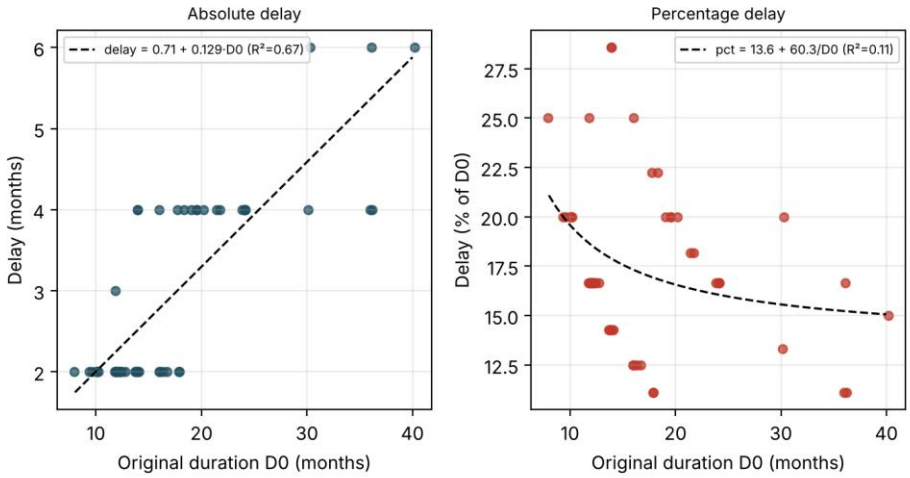

Figure 3. Delay versus original duration, in absolute (left) and percentage (right) terms. Points are jittered horizontally for visibility.

4.5 Cost–schedule coupling

Pearson correlation between cost and schedule growth percentages was 0.566 in the companion analysis; the rank correlation here is lower ($\rho = 0.40$, $p = .004$), indicating that a few high-leverage projects strengthen the linear estimate. In logarithmic form, the duration ratio rose with the cost ratio with an elasticity of 0.38 (SE 0.083; $R^2 = 0.31$; $p < .001$): a 10% increase in cost ratio was associated with about a 3.8% increase in duration ratio. In absolute units, delay months rose 0.66 per EGP billion of added cost ($R^2 = 0.71$), but both quantities scale with project size, so this figure should not be read as a causal rate.

5. Discussion

Three practical points follow. First, reserves should be set from percentiles with their uncertainty. In this reference class, a reserve at the mean covers 56% of projects, and moving from P50 to P90 raises the project-level reserve from 22.5% to 33.3% of original cost. The width of the P80 interval (25.0–33.3%) shows that 50 projects do not pin the upper tail down tightly, which argues for updating the reference class as new projects complete. This is consistent with the case for reference class forecasting against optimism bias (Flyvbjerg, 2008) and extends it from total cost growth to change-order growth.

Second, pooling matters. A programme-level reserve near 25.5% would have covered 95% of resampled programmes, below the project-level P80. This supports holding part of the contingency centrally. The result depends on independence between projects; common drivers such as input price shocks, shared contractors, or policy-driven scope expansion would raise correlation and narrow the benefit, so the figures here are a lower bound on the required programme reserve.

Third, schedule buffers should not be a flat percentage. Delay behaved as a fixed component plus a duration-proportional component, so a single percentage overstates delay for long projects and understates it for short ones. This reconciles with the size pattern in percentage delay: the smaller projects show higher percentage delay because a similar absolute delay is divided by a smaller base. It also qualifies the use of percentage schedule growth as a comparison metric across projects of different length, and cautions against comparing it directly with percentages reported elsewhere. The moderate elasticity (0.38) indicates that schedule buffers cannot be derived from cost reserves by a simple proportion.

Limitations. (i) The values show rounding: 18 of 50 cost-growth values are exactly 20% or 25%, and 49 of 50 delays are even numbers of months, which suggests that some figures may be approved or planned values rather than measured outturn, and the 'after' values for ongoing projects may be forecasts. Percentile estimates are therefore less precise than their formal intervals imply, and the discreteness of delay limits the regression fit. (ii) Records are aggregated by project, with no count, timing, or initiator of individual change orders. (iii) With $n = 50$, tails above P90 are poorly determined. (iv) Independence is assumed in the pooling analysis. (v) The sample covers one authority and country; the figures should be treated as a starting reference class, not a universal benchmark. (vi) The analysis is descriptive and does not identify causes.

6. Conclusions

Using 50 Egyptian highway and bridge projects as a reference class, the study finds that project-level change-order cost growth has a median of 22.5%, a P80 of 27.1%, and a P90 of 33.3%; that programme-level pooling reduces the required reserve to about 25.5% at the 95th percentile under independence; that schedule delay is better described as 0.7 months plus about 13% of original duration than as a fixed percentage; and that duration growth responds to cost growth with an elasticity of about 0.4. For practice, owners should set reserves from percentiles, hold part of them at programme level, and model schedule buffers with a fixed and a proportional term. Future work should use itemised, dated change-order records to test these results with measured outturn data, and should test whether contract type and delivery method shift the percentiles.

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