Setbacks, Shutdowns, and Overruns

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NBER Organizations: April 2021

1. University of Washington
2. Duke University

Sydney Opera House, 10 years late and more than 14 times over budget

Berlin's Brandenburg Airport, scheduled to open 2012 and budget for 2.8b euro; complete in 2020, costing nearly 8b

Boeing 787 Dreamliner program, 3 years late and double its estimated cost

"setbacks are a near-universal, and universally costly, experience . . . large capital projects are typically 20 months late, and 80% over the original authorized budget." Billante (2017)

South Carolina's V.C. Summer nuclear power plant. Cancelled in 2017 after costing $9b

The FBI VCF project. Cancelled after 5 years and cost $170m

"According to a 2017 report from the Project Management Institute, 14% of IT projects fail… Of the projects that didn't fail outright, 31% didn't meet their goals, 43% exceeded their initial budgets, and 49% were late"

Hofstadter's Law: It always takes longer than you expect, even when you take into account Hofstadter's Law.

Projects and Setbacks in Practice: Common Features

- Projects require *resources* (labor, equipment, materials) to develop and *time* to complete.
- The final product is contractually verifiable (a building that is habitable, a machine that runs; a software program that works).
- But the state of progress prior to completion is only observed by the contractor.
- Development is subject to setbacks, which arise naturally but randomly (i.e., not due to negligence or malfeasance).
  - Construction $\rightarrow$ Adverse site conditions.
  - Software application $\rightarrow$ Incompatibility of off-the-shelf packages.
  - Research paper $\rightarrow$ Missing or corrupted data.

Agency Frictions

- The contractor (**A**) has limited liability and can:

  1. Shirk: diverting resources for personal benefit (hire friends and family, spend on perquisites, work on other projects).

  2. Mis-report the state of the project: claim false setbacks or delay disclosing real ones.

- The problem for the sponsor (**P**): design an optimal contract that deters shirking & induces truthful & timely reporting.

- **The solution**: use two instruments: a time budget (stochastic deadline) and a reward for completion.

Some Possible Contracting Options

1. Offer payment for completion, but no deadline.
   Problem: absent discounting, **A** will report false setbacks and shirk forever.
2. Offer payment for completion, and a *hard* deadline.
   Problem: a late-stage setback will make completion infeasible and induce **A** to 'shirk out the clock.'
3. Offer payment for completion, a hard deadline, and severance for a reported late-stage setback.
   Problem: **A** will truthfully report a late-stage setback, but the project will be canceled for sure in this case.
4. Offer payment for completion and randomize between cancellation and extension if a late-stage setback is reported.
   Optimal! **A** will truthfully report a late-stage setback and the project will be completed with positive probability.

Preview of Main Results

- **Overruns** (in terms of time and budget): may need to fund the project after granting multiple extensions.

- **Shutdowns**: project may be canceled even after running arbitrarily long.

- **Cost-plus-award-fee contract**: cost-reimbursement + a fixed payment upon completion + a variable reward (for early completion).

- **The role of commitment:** if commitment to randomization probabilities is not possible, **P** optimally commits *more* time and resources to the project, even though it is less valuable to her.

Related Literature

- Optimal project management and deadlines: Green and Taylor (2016), Madsen (2020), Mayer (2020), Sinander and Curello (2020), etc.
  - A Poisson event (breakthrough, failure, permanent change of state, etc.) privately observed by **A**.
  - Core problem: how long should **P** wait before taking actions *in the absence of* the reported event?
- Main differences with our paper:
  1. **A**'s private information (the progress) is *persistent*.
  2. Potentially infinitely many reported (true or false) Poisson events (the setbacks).

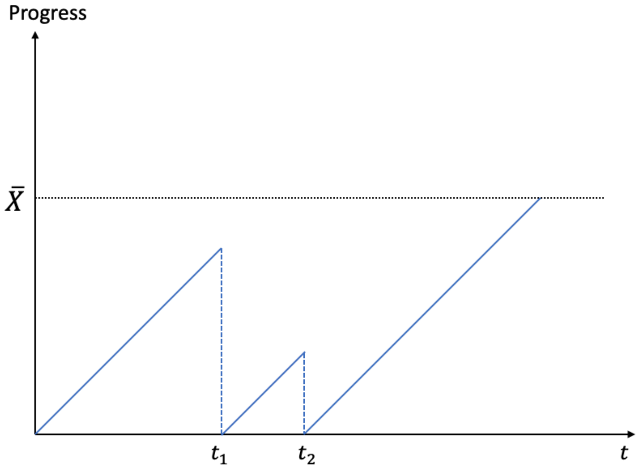
Model (1/2)

- **P** hires **A** to develop a project.
- Both parties risk-neutral, but **A** has limited liability.
- Continuous time, infinite horizon, no discounting.
- Common knowledge that project completion requires accumulated progress of duration $\bar{X}$.
- **P** gets R from a complete project and 0 from an incomplete one.

Model (2/2)

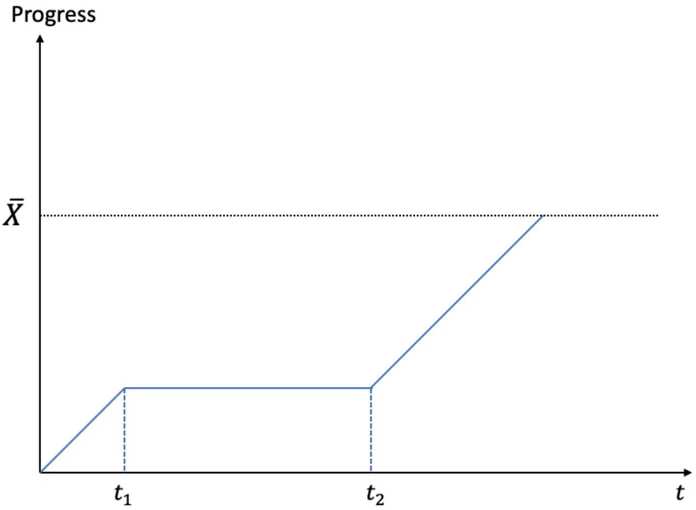
- If **A** works ($a_t = 1$), progress X_t accumulates over time, but setbacks are discovered via a Poisson process N_t at rate λ, resetting $X_t = 0$.
- If **A** *shirks* ($a_t = 0$), progress remains stationary at X_t, no advancement and no setbacks.
- $dX_t = a_t(dt - X_t dN_t)$; $a_t \in \{0, 1\}$.
- Project requires flow investment c to advance, but **A** can privately divert this ($a_t = 0$) and get flow benefit $b < c$.
- Progress and setbacks observable only to **A**, but completion is verifiable.

Sample Path (Full Effort)



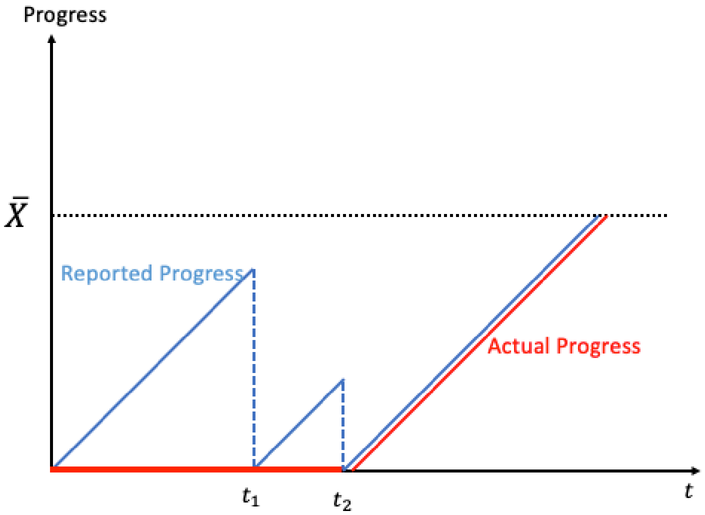
A Sample Path of Progress under Full Effort

Sample Path (Shirking)



A Sample Path of Progress with Shirking

Sample Path (Shirking and Misreporting)



Actual Progress Trajectory vs Reported Progress Trajectory

Full and Asymmetric Info

- If progress were observable and the project run until completed, **P** would expect:

$$\begin{aligned} F^{\mathsf{FB}} &= \int_0^{\bar{X}} \lambda e^{-\lambda X}(-cX + F^{\mathsf{FB}})\, dX + e^{-\lambda \bar{X}}(R - c\bar{X}) \\ &= R - \frac{c}{\lambda}\left(e^{\lambda \bar{X}} - 1\right) \end{aligned}$$

- If $F^{\mathsf{FB}} > 0$, then:
  - It is optimal to start the project.
  - It is never optimal to stop the project before completion.
- Under asymmetric info, a stronger assumption is needed:

$$F^{\mathsf{FB}} > \frac{b}{\lambda}\left(e^{\lambda \bar{X}} - 1\right) \equiv K_0$$

- **A** can be fired w/o payment if he is *detected* shirking or lying.
  - i.e., spend $\bar{X}$ time w/o delivering the product or reporting a setback.

Contract

- $\mathcal{C}$ Specifies a termination time τ, terminal payment K_τ, and any intermediate payment C_t.
- Given $\mathcal{C}$, **A** maximizes expected compensation plus private benefits from shirking:

$$W_t = E\left[\int_t^\tau b(1-a_s)ds + \int_t^\tau dC_s + K_\tau\right]$$

  - W_t: **A**'s *continuation utility*.
- **P** maximizes expected payoff from project completion minus compensation and operating cost:

$$F_t = E\left[-\int_t^\tau cds + R_\tau - \int_t^\tau dC_s - K_\tau\right] ,$$

  - $\mathcal{C}$ is incentive compatible if **A** never shirks or lies.
  - $\mathcal{C}$ is optimal if it is incentive compatible and maximizes F_t.

A's Continuation utility

- LEMMA 1: $\mathcal{C}$ is optimal only if no intermediate payments, $dC_t = 0$.

- With no intermediate payments, the evolution of W_t can be written as:

$$dW_t = \underbrace{\lambda J_t dt}_{\text{progress}} - \underbrace{J_t dN_t}_{\text{setback}}$$

- J_t: the size of **A**'s utility jump down when a setback occurs.

The "No-Postpone-Setback" Constraint

$$-J_t \geq b\Delta + \int_0^\Delta \lambda J_{t+s} ds - J_{t+\Delta}, \quad \forall \Delta \in (0, \bar{X} - X_t). \qquad \text{(NPS)}$$

- NPS comes from comparing two paths following a setback:
  1. [Work, LHS] Report the setback immediately, and continue working.
  2. [Shirk, RHS] Postpone reporting the setback and shirk for time $\delta \leq \bar{X} - X_t$. Then report a (bigger) setback & resume working.
- We show that binding NPS:
  - corresponds to an ODE with solution $J_t(X) = \frac{b}{\lambda}(e^{\lambda X} - 1)$, $\forall t$,
  - implies **A** also prefers not to report false setbacks,
  - and is optimal!

Optimal Contract: A Time Budget

- **time budget** (S_t) is critical for the implementation of an optimal contract.
  - A time budget is a stochastic deadline that either counts down deterministically or jumps up or down randomly (with zero mean).
  - A time budget creates a random stopping time τ when the contract is terminated (upon completion or cancellation)

Proposition 1

The optimal contract has the following properties:

(i) *Implemented with a time budget such that $bS_0 = W_0$ and **A** is terminated if $S_t = 0$ and no delivery.*

(ii) *If $S_{t-} < \bar{X}$ and a setback is reported, then S_t is set to either 0 with probability $1 - p$ or $\bar{X}$ with probability p where $p = \frac{S_{t-}}{\bar{X}}$*

(iii) *If **A** delivers the project he receives reward $K_\tau = K_0 + bS_\tau$*

Initial Value of the Project

- $P(S)$: probability that the project is completed given $X_t = 0$.
  - $P(S)$ is increasing and concave.
  - $P(S)$ has kinks at multiples of $\bar{X}$.
  - $P(S) \to 1$ as $S \to \infty$.

Proposition 2
P*'s valuation of time budget S when $X = 0$ is*

$$F(S, 0) = P(S)F^{\textsf{FB}} - bS$$

- Bigger $S \implies$ higher completion probability $P(S)$, but higher agency rents bS.

Relaxing Commitment

- Suppose randomization by **P** or **A** is possible but not verifiable.
- Consider a mixed-strategy equilibrium when setbacks are reported for $S_{t-} < \bar{X}$:
  - **P** randomizes between extension or cancellation just as under commitment,
  - When receiving an extension, **A** randomizes between working or shirking until $S_t = 0$.
- Setback at $S_{t-} < \bar{X}$, **A** gets same expected payoff, but **P**'s expected payoff is zero!
- So **P**'s value is lower for all S compared with commitment, but she optimally responds by setting initial S_0 **higher**.
  - **P** increases S_0 to raise the prob. of completion before $S_t < \bar{X}$.
  - To mitigate lack of commitment, **P** doubles down on the part of the contract she *can* commit to.

Conclusion

- Agency frictions are indemic to project management.
  - *Sponsors* seldom possess the ability to assess progress or to observe the occurance of setbacks.
  - *Contractors* can obtain rents by manipulating the timing and veracity of reported setbacks.
- We study optimal project management in such a setting.
  - Optimal mechanism: a time budget and a linear terminal payment corresponding to a cost-plus-award-fee contract.
  - Mishaps reported near the end of the allotted schedule either result in project cancellation or minimally feasible extension.
  - Probability of cancellation is higher for later reported setbacks.

Although overruns & cancellations are commonly viewed as failures, we argue that *they are necessary features of optimal project management*.