The Value of Flexibility in System Design for a Resource Corridor Program

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Public-Service Infrastructure Systems

• Key attributes that make design and capital budgeting for infrastructure projects (power, water, transportation, etc) difficult:

  – Systems & projects are long-lived technically and economically => risk!
  – Volatility in natural resource/commodity availability => risk!
  – Capital intensity & capital recovery requirements => risk!
  – Physical, technical & financial interdependencies => risk!
  – Public goods and services are difficult in terms of pricing, cost recovery, and benefit allocation => risk!
  – Institutional arrangements are shifting, or even turbulent => risk!

• Fundamental needs and goals of projects, and those of stakeholders, may evolve uncertainly over time!

• Infrastructure project design and execution remains challenging, in spite of available sophistication in engineering, finance and institutions

Central Theme

How to approach the design of public-service infrastructure projects / systems under conditions of deep uncertainty and risk?

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<table>
<thead>
<tr>
<th><strong>Traditional Procurement</strong></th>
<th><strong>Flexibility in System Design</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Identify needs today, fix output/service specifications based on forecasts</td>
<td>• Identify needs, but recognize that they may change; the forecast is always wrong</td>
</tr>
<tr>
<td>• Define, design, and move to execute <em>today!</em></td>
<td>• Phased approach – execute some today, defer some important decisions until <em>later!</em></td>
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<tr>
<td>• Emphasizes finding optimal cost-value tradeoff <em>ex ante</em>, before major uncertainties are resolved</td>
<td>• Emphasizes improving life-time performance and value by making decisions contingent on new information about uncertain factors</td>
</tr>
<tr>
<td>• Requires stakeholder pre-commitment to full sequence of decisions, before major uncertainties are resolved</td>
<td>• Requires stakeholder commitment to re-evaluating decision options, and monitoring how uncertainties are resolved</td>
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<tr>
<td>• Offers little to no flexibility to re-direct performance trajectory</td>
<td>• Offers opportunities to re-direct the course of the system</td>
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*The greater the degree of uncertainty, the more valuable the flexibility*
Key Principles

Given the challenges, the proposed approach of “flexibility in system design” relies on three key principles:

• **Incorporate uncertainty analysis**
  – Treating uncertainties as front and center in evaluating projects, instead of avoiding or side-stepping, in early-stage planning & design

• **Broaden the system boundary**
  – Acknowledge and evaluate effects of interdependencies between various aspects of system, and effect of projects on system performance

• **Employ phased ‘option’-based decision-making**
  – Commence project preparation, but avoid lock-in by gradually escalating commitment from front-end planning to execution

This work demonstrates the analytical approach that can guide project preparation and execution using ‘resource corridors’ as an example
Resource Corridor Programs & Flexibility?

- An opportunity for flexibility in design...move beyond individual projects, towards program of opportunities => broaden the system boundary

- Realizing full program is contingent on executing a series of (sometimes interdependent) individual projects in phases

**Example: Simple Resource Corridor with Two Project Options A & B**

- Objective: Maximize value to system, not necessarily to individual projects, given that future is uncertain

- Which approach?
  - Do A only? Do B only? Do A & B?
  - Do A first, or B first, and when?

Can we find a strategy that is robust, i.e. creates a win-win situation irrespective of how the uncertain future evolves?
Resource Corridor Programs & Flexibility?

Continuing same example: Simple Resource Corridor with Two Project Options A & B

<table>
<thead>
<tr>
<th>Traditional Procurement</th>
<th>Strategy</th>
<th>Expected Outcome</th>
<th>Project</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate Individually</td>
<td></td>
<td></td>
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<tr>
<td>Project A</td>
<td>1: Do Nothing</td>
<td>Not valuable</td>
<td>A</td>
<td>Do Nothing</td>
</tr>
<tr>
<td></td>
<td>2: Execute</td>
<td>Valuable</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Project B</td>
<td>1: Do Nothing</td>
<td>Not valuable</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>2: Execute</td>
<td>Valuable</td>
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<table>
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<tr>
<th>Flexibility in Resource Corridor System Design</th>
<th>Strategy</th>
<th>Project Value</th>
<th>System Value</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate as a System</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Project A</td>
<td>1: Do Nothing</td>
<td>Value1</td>
<td>Value1 = - -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2: Only A</td>
<td>Value2</td>
<td>Value2 = - -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3: Only B</td>
<td>Value3</td>
<td>Value3 = +</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4: A &amp; B today</td>
<td>Value4</td>
<td>Value4 = -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5: A first, then B</td>
<td>Value5</td>
<td>Value5 = -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6: B first, then A</td>
<td>Value6</td>
<td>Value6 = + +</td>
<td></td>
</tr>
</tbody>
</table>

Decision

‘B first, then A’
A robust strategy because if B succeeds ‘+’ is gained, and if A also succeeds ‘++’ is gained, but no losses occur

A Win-Win Strategy!
Phased ‘Options’-based Approach

Schematic of flexible procurement process with options to escalate/iterate/abandon at each phase

- **Concept**: Lower cost, easier to alter/iterate/abandon
- **Feasibility**: Escalate to Design
- **Design**: Escalate to Execution
- **Execution**: Abandon
- **Construction, ramp up & operations**: Abandon

Level of escalation in procurement process

- **Degree of Commitment / “lock in”**
  - Project Preparation
  - Design
  - Execution

Final decision to execute is easier when project preparation is complete, but pre-commitment to execute can be costly => retain flexibility!

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Implications of a ‘Flexibility in System Design’ Approach

Need to look for win-win strategies by:

- Broadening system boundary
- Identifying relevant system strategies comprised of decision alternatives
- Identifying appropriate performance metrics, ex. Net Present Value
- Focusing on performance consequences of uncertainty drivers, not drivers themselves
- Establishing framework for monitoring performance, and establishing future decision points for exercising “options”

Note:
Waiting for uncertainties to resolve is not the same as “doing nothing”. Rather, ‘deferring’ implies preparing *today* to execute on opportunities in the future. Preparations come at a cost, albeit significantly smaller than the full cost of execution.
Case Example: Afghanistan Resource Corridor Program

Northern hydrocarbons

North-West extension (copper/hydrocarbons)

Cross Hindu Kush

Steel & energy

Nama-Shaida

Sya Dara

Balkhab

Ishpushhta

Affgan-Tajik

Qara Zaghan

Focus on linkages between Kabul’s water system & Aynak copper mine

North-West extension (copper/hydrocarbons)

South-West extension: rail for large-scale Hajigak exports – needs several positive geopolitical developments

South-East Copper segment

South-East Copper segment

South-East extension: depends on scale of copper and lithium deposits (power needs, for example could be leveraged for South-East Power System)

Corridor segments

- Northern hydrocarbons
- South-East Copper
- Cross Hindu Kush
- Steel & energy link
Kabul Water System Development Context

• Water Demand
  – Uncertain growth in domestic & agricultural water demand (in 2012: 45 MCM/year)
  – Aynak copper mine will impose small but steady water requirement (10 – 12 MCM/year)
  – High proportion of physical losses (35%) and unaccounted for water (30%) in urban distribution system

• Water Supply
  – Withdrawals from Kabul area groundwater source at maximum safe yield limits, but aquifer becoming increasingly polluted
  – New supply in near term (~ 2 - 5 years) from nearby Middle and/or Upper Logar aquifers
  – Storage reservoir – Shatoot Dam on Maidan River – is a mid-term alternative (~ 5 - 10 years)
  – New supply sources require a combination of conveyance, treatment and enhancements in distribution to meet demand

• System Development Strategies
  One or more combinations of the following
  – Enhance Kabul area water distribution system
  – Develop new wells in Middle and/or Upper Logar Aquifers
  – Build Shatoot Dam
Issue: how to develop Kabul’s water system under demand uncertainty?

Kabul Area Water System

- Build Shatoot Dam?
- Develop Upper Aquifers?
- Enhance water distribution system?
- Severeely supply constrained groundwater system

City of Kabul

= project options  = key contextual factors

= interdependencies/ linkages

Dam

Aquifers

Aynak Copper Mine

Note: The value shows GW potential for water supply for the Kabul metropolitan area.

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System Strategies Evaluated

1. What is the effect of ‘doing nothing’?
   - A counterfactual or reference frame to provide a benchmark of system value or performance

2. Should the distribution system be enhanced?
   - Without new supply options?
   - With new supply options? If so, which ones?

3. Should the middle + upper Logar aquifers be developed?
   - Needs distribution system enhancements to meet demand

4. Does the Shatoot Dam improve system performance?
   - Without aquifer development? If so, small or large dam?
   - With aquifer development? If so, small or large dam? Aquifer or dam first?

5. Do the outcomes change if Aynak is included as a part of the water system?
   - Endogenize demand and tariff revenues from mine to study effect on system strategies above
Analytical Approach

1. Simulated uncertain evolution of water demand
   - Geometric Brownian Motion (“random walk processes”) with initial demand beginning at 45 MCM/year, growth rate at 4%/year, 2% volatility in growth
   - Generated 10,000 possible stochastic scenarios/paths of demand evolution over study horizon of 35 years
   **Result:** water demand state-space used for valuation in Step 2

2. Evaluated effect of strategies on system value (NPV) based on uncertain demand evolution, uncertain aquifer yields
   - Exclude Aynak from System
     - Enhance distribution system?
       - Develop aquifers?
         - Build dam?
   - Include Aynak in System
     - Enhance distribution system?
       - Develop aquifers
         - Build dam?
   **Result:** probability distribution of system value under each strategy

3. Identified possible robust ‘win-win’ strategies
   **Result:** a strategy that is conducive to phased, ‘option’-based decision-making

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# Critical Assumptions

Results are obtained using conservative estimates

<table>
<thead>
<tr>
<th>Category</th>
<th>Values (all values in USD)</th>
</tr>
</thead>
</table>
| Supply           | • Kabul, Logar aquifer yields all modeled as uncertain  
                  • Middle + Upper Logar developed upto 50% of potential yield                                                                                                                                                     |
| Benefits         | • Potable water price $ 26 / cu. m. for 5% of total demand  
                  • Shadow price of unmet domestic demand $ 0.35 / cu. m.  
                  • Aynak water tariff $ 1 / cu. m.                                                                                                                                      |
| Capital costs    | • Distribution system phased over 10 years costs $ 660 million inclusive of sewerage and treatment  
                  • New aquifer development costs $ 70 million, based on development of 50% of total aquifer potential  
                  • Shatoot Dam costs either $235 million (180 MCM, small) or $ 318 million (250 MCM, large)                                                                 |
| Discount rates   | • Sensitivity analysis using 5, 7.5 and 10 % p.a.                                                                                                                                                                       |
Water Demand – the primary driver

Water sector investments in the Kabul area are motivated by the current and expected future demand/supply imbalance.

But the forecast is always wrong!

- Demand evolves, it cannot be predicted
- Supply sources such as aquifers and storage reservoirs exhibit natural variance
- State-space of 10,000 possible demand growth paths over study horizon of 35 years is used, shown three as examples
Effect of “doing nothing”?

Understanding the counterfactual of not exercising water system strategies:

- Latent value of unmet domestic water demand due to severely constrained supply
- Health effects of increasingly polluted groundwater
- Physical losses and economic inefficiencies in water delivery
- Missed future economic opportunities

Doing nothing implies lost social value from unmet demand!
Enhance Kabul’s Water Distribution System?

Distribution system investment implications:

- High capital costs, even if build out is phased over 10 years
- Inability to meet new demand due to already constrained supply
- In absence of new supply, no incentive for users to substitute away from continuing to extract groundwater
- Minimal overall efficiency and health improvements as a consequence

System is worse-off by enhancing distribution system in the absence of new supply sources
Develop Aquifer Option as New Supply Source?

Sourcing new supply from aquifers is largely value-positive, provided an enhanced distribution system is phased in to deliver new supply.

Phasing in an enhanced distribution system to receive new supply enables:

- Health benefits: substitution from increasingly polluted Kabul area ground water to cleaner & treated water from upper Logar aquifers

- Efficiency improvements: reduced physical water losses and unaccounted-for water
How does the Shatoot Dam compare as a supply source?

In comparison to aquifers, dam is riskier & mostly value-negative... and larger dam is worse!

Pursuing the Shatoot dam first is less valuable than developing the aquifers, irrespective of dam size:

- Dam is more expensive, longer time to operation, has more significant operating and cost recovery implications and very little upside.
Simultaneous dam and aquifer development?

Aquifer development only with distribution system enhancements is the dominant strategy

- if aquifers are being or have already been developed, adding the dam NOW imposes high capital costs while minimally increasing benefits

- Caveats:
  - Assumes no delays in delivering Shatoot dam - an unlikely assumption
  - Including Aynak mine in system may alter results

Valuation of Water System Strategic Options @7.5 %

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What if Shatoot execution is phased to 5 years later?

Preparing Shatoot now, but executing final build decision later, in addition to aquifer development, actually makes it more valuable if and only if water demand is high. Demand is expected to be higher further out in time.

Phase Shatoot dam development so that final execution decision for Shatoot is after aquifer development
Aquifer development with distribution system enhancements tends to dominate, irrespective of discount rate.

- Dam options are always riskier.
- Aquifer development tends to limit downside, i.e. lost social value due to unmet demand in the near-to-mid-term.

Results robust to discount rates?
Effect of including Aynak in system?

Relatively stable increased water demand from Aynak requires an increase in supply when Kabul’s water demand is also high. Higher implicit value (tariffs) of uninterrupted supply water to Aynak makes the dam valuable. In fact, phased Shatoot deployment in addition to aquifer development is most valuable strategy with Aynak included in the system.

Benefits of uninterrupted water supply to Aynak cross-subsidize Kabul water system development

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Summary of Analysis

• Kabul water system modeled with and without Aynak mine as part of the system

• Uncertainty analysis & system strategy evaluation performed

• A robust strategy emerged:
  – Enhance distribution system in phases to receive new water supply
  – Simultaneously begin Logar aquifer development in preparation and execution phases
  – Prepare (feasibility, design, relocations, etc.) smaller Shatoot dam (180 MCM), while planning to make final execution decision in mid-term (~ 5 years)

Kabul Water System

- Distribution System: Execute phase 1, prepare phase 2...
  - Option to execute phase 2, prepare phase 3...

- Logar Aquifers: Prepare Middle aquifer project
  - Execute Middle, prepare Upper
  - Option to execute Upper

- Shatoot Dam: Prepare Shatoot Dam
  - Option to execute dam

2012  2014  2017  2022  ....

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Concluding Remarks

• Value of ‘Flexibility in System Design’ demonstrated in Kabul Water System case:
  – Retaining flexibility is valuable precisely because the future is uncertain, here water demand & aquifer yields
  – Broadening the system boundary to include multiple discrete project options (and even the Aynak mine) demonstrated a strategy that maximizes value to the whole system
  – A phased approach allows preparation for future opportunities, while simultaneously meeting current needs

• Analytical and implementation approach generally applicable to Afghanistan Resource Corridor, other multi-project/multi-system situations that are common in infrastructure and extractive industries
# Detailed Assumptions

## Overall

- **Study horizon**: 35 years, 2012 – 2047
- **Method**: Probabilistic Monte Carlo simulation
- **Discount rates tested**: 5, 7.5 & 10%

## Kabul Area Water Demand

- **2012 domestic demand**: 45 MCM/year
- **Annual growth rate**: 4%
- **Annual volatility in demand**: 2%
- **Potable water demand**: 5% of domestic consumption
- **Aynak mine demand**: 10 MCM/year average

## Water Resource – Unit Benefits & Costs

- **Potable water**: USD 26 / cu. m. (i.e. per 1000 liters)
- **Untreated water**: USD 0.20 / cu. m.
- **Treated non-potable water**: USD 0.35 / cu. m.
- **Shadow price of demand**: USD 0.35 / cu. m.
- **Aynak water price**: USD 1.00 / cu. m.
Main Assumptions (2)

Water Distribution & Wastewater Treatment System

- Existing efficiency / losses: 65% - i.e. only 6.5 of every 10 cu. m supplied reaches consumer
- Efficiency after enhancements: 80%
- Capital Expenses (CapEx): USD 660 million, including sewerage
- Phased enhancements: 20% delivered every 2 years, over 10 years
- Operating costs (OpEx): 2% of total CapEx / yr

Aquifer Supply

- Kabul (lower Logar/upper Kabul): Uncertain yield around 40 MCM / yr, log-normally distributed
- Middle + Upper Logar aquifers: Additional 35 MCM / yr, log-normally distributed
  - approx. 30% of estimated potential yield from Middle+Upper
  - approx. 60% of estimated yield from Upper only
- Development CapEx: USD 65 million, assumed no operating expenses

Shatoot Dam (180 or 250 MCM / year nominal)

- Effective available supply: 70% of nominal capacity i.e. 126 MCM or 175 MCM / yr
- CapEx for “small” (180 MCM/yr): USD 235 million, USD 282 million (with 20% contingency)
- CapEx for “large” (250 MCM/yr): USD 318 million, USD 383 million (with 20% contingency)
- OpEx for both options: 1% of total CapEx / yr