R&D Project Planning with Multiple Trials in Uncertain Environments

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Problem Statement

• Goal = maximize NPV of projects in which:
  – Activities can fail
  – Activities that pursue the same result may be grouped in “modules”
  – Each module needs to be successful for the project to succeed
  – A module is successful if at least one of its activities succeed
    ⇨ Not all activities in the network have to be started in order for the project to be successful
    ⇨ Upon failure of all activities in the module, the module fails, resulting in overall project failure

• This is common in R&D (especially in NPD) but also in other sectors: pharmaceuticals, software development, fundraising, ...

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- $m$ modules $N_i$
Solution methodology

- Exponentially distributed durations => use of a Continuous-Time Markov Chain (CTMC) to model the statespace
- State of an activity $j$ at time $t$ can be:
  - Not started
  - In progress
  - Past (successfully finished, failed or considered redundant because another activity of its module has completed successfully)
- Size of statespace has upper bound $3^n$. Most states do not satisfy precedence constraints => a strict definition of the statespace is required and provided in Creemers et al. (2010)*

⇒ Backward SDP-recursion

Project value upon entry of the final state = project payoff

(2,2,2,2,0) [450M$]
Discount factor: \((1/D_j)\cdot(r+(1/D_j))^{-1}\)

\[D_4 = 2 \implies \text{discount factor} = 0.83\]

NPV upon state entry if success = 375

\[p_4 = 0.85 \implies \text{NPV upon state entry} = 318.75\]
Discount factor: \( (1/D_j) \cdot (r + (1/D_j))^{-1} \)

\[ D_3 = 2 \Rightarrow \text{discount factor} = 0.83 \]

NPV upon state entry if success = \( 375 \)

\[ p_3 = 1.00 \Rightarrow \text{NPV upon state entry} = 375 \]

\( (2,2,2,2,2,0) \) [450 M$]

\( (2,2,2,2,1,0) \) [318.75 M$]

\( (2,2,2,1,2,0) \) [375 M$]
Discount factor = 0.91
Probability of finishing activity j first = \((1/D_j) \cdot (\Sigma (1/D_{ij}))^{-1}\)

\(0.5 \times 0.91 \times 1.00 \times 318.75 = 144.89\)

\(0.5 \times 0.91 \times 0.85 \times 375 = 144.89\)

\(\Rightarrow\) NPV upon state entry = 289.77
3 possible decisions (pick the optimal one):

- Start activity 3 => incur cost $c_3 = -5\text{M}\$ 
  => end up in (2,2,1,2,1,0)

- Start activity 4 => incur cost $c_4 = -5\text{M}\$
  => end up in (2,2,2,0,1,0)

- Start activity 3 & 4 => incur cost $c_3 + c_4 = -10\text{M}\$
  => end up in (2,2,2,1,1,0)[289.77\text{M\$}]
The optimal policy yields the following decision tree.
Results & Future Work

• Computational results:
  – 1260 randomly generated projects have been solved to optimality

<table>
<thead>
<tr>
<th>$n$</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>60</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU (sec)</td>
<td>0.00</td>
<td>0.03</td>
<td>1.95</td>
<td>84.04</td>
<td>4100.52</td>
</tr>
</tbody>
</table>

  – Main determinant of computation time = network density (for fixed $n$)

• Future work:
  – Using the model to generate insights
  – General activity durations using Phase-type distributions
  – Renewable resources