R&D project evaluation: An integrated DEA and balanced scorecard approach*

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R&D project evaluation problem

- Multiple criteria (reward, relevance, leverage potential, probability of success…)
- Need to weight the criteria to reflect the intended emphasis of the organization
- The focus is on future events and opportunities
- Dynamic environment
- Uncertain information
- Multiple stakeholders (sometimes with conflicting goals)
- Quantitative and qualitative measures
Literature review

- Mathematical programming:
  MIP, NLP, DP
- Economic models:
  NPV, IRR, ROI
- Scoring models
- Decision analysis:
  MAUT, AHP, Decision trees
- Behavioral approaches:
  Collective DM, Delphi, Q-Sort
- Mapping approaches:
  Bubble diagrams, Visual support systems
- DEA related methods
Limitations in the proposed models

- Inadequate treatment of risk and uncertainty
- Inadequate treatment of multiple, often interrelated, criteria
- Inadequate treatment of project interrelationships
- Inability to treat non-monetary aspects, such as establishing balance in the R&D portfolio
- Perception that the models are unnecessarily difficult
- Inadequate treatment of the time variant property of data
Objective

• To develop an analytical model aimed at evaluating R&D projects in different stages of their lifecycle:
  – Project proposals – as part of a project selection phase
  – Ongoing projects – during their initiation, planning, execution or closing stages
Data Envelopment Analysis

**CCR Input Oriented Ratio Form, DEA Model**

\[ \begin{align*}
\text{Max} & \quad w_0 = \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \\
\text{s.t.} & \quad 0 \leq \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \leq 1 \quad \forall j \\
& \quad u_r, v_i \geq \varepsilon
\end{align*} \]

- Linear programming-based technique
- Generalize the single-output/input ratio measure of efficiency to the multiple-output/input ratio
- Optimizes on each individual observation
- Construct an empirically based production frontier by the identification of peer groups

\[ u_r \quad \text{weight given to output } r \]
\[ y_{rj} \quad \text{amount of output } r \text{ produced by project } j \]
\[ v_i \quad \text{weight given to input } i \]
\[ x_{ij} \quad \text{amount of input } i \text{ consumed by project } j \]
Data Envelopment Analysis: Example

- Pareto optimality
- Efficient frontier
- Hypothetical comparison unit
- Efficiency measure
- Reference set

These concepts are easily extended to higher dimensions and are thus applicable in a multiple-input, multiple-output systems.

Efficient frontier for a production process with two outputs and a single input.
Balanced Scorecard

• Created by Kaplan and Norton of Harvard Business School in the early 90’s
• Originally adopted by organizations to improve their performance measurement systems
• From measurement system to management system
Balanced Scorecard (cont’d)

• Minimize information overload by limiting the number of measures used (typically …)
• Brings together many seemingly disparate elements of the evaluation
• Guards against sub-optimization by considering all the important measures together
• Provides the ability to see whether improvement in one area may be achieved at the expense of another
The BSC* Concept

* Balanced Scorecard, Kaplan and Norton (1992), HBR
The use of the BSC for R&D projects

• At the selection phase:
  – Clarify and translate the strategy plan into tactical objectives
  – Sets appropriate criteria for project’s evaluation
  – Includes forward-looking measures (estimates, subjective judgments)

• At the execution phase:
  – Evaluates the value of the projects in the face of changing circumstances and priorities
  – Communicate the results (accountability)
  – Includes a mix of backward-looking and forward-looking measures

• At the closing phase:
  – Identify best practices
The DEA-BSC Model

Maximize (Ratio of Outputs to Inputs)

\[
\max_{u,v} s_0 = \sum_{r} u_r y_{r0}
\]

s.t.

\[
\begin{align*}
\sum_{i \in C_k} y_{i0} &= 1 \\
\sum_{r} u_r y_{rj} - \sum_{i} v_i x_{ij} &\leq 0 \quad \forall j \\
- \sum_{r \in C_k} u_r y_{r0} + L_{C_k} \sum_{r \in C_0} u_r y_{r0} &\leq 0 \quad k = 1, \ldots, \bar{k} \\
\sum_{r \in C_k} u_r y_{r0} - U_{C_k} \sum_{r \in C_0} u_r y_{r0} &\leq 0 \quad k = 1, \ldots, \bar{k} \\
u_r &\geq \varepsilon \\
v_i &\geq \varepsilon
\end{align*}
\]
The DEA-BSC Model (cont’d)

\[
B_v = \begin{pmatrix}
1 - U_{c_1} & -U_{c_2} & \cdots & -U_{c_r} \\ 
1 - U_{c_1} & -U_{c_2} & \vdots & \vdots \\ 
-1 & -U_{c_2} & \cdots & \cdots \\ 
-1 & -U_{c_2} & 1 - U_{c_r} & \cdots \\ 
-1 & -U_{c_2} & \cdots & \cdots \\
\end{pmatrix}
\[
B_k = \begin{pmatrix}
-1 + L_{c_1} & L_{c_2} & \cdots & L_{c_r} \\ 
-1 + L_{c_1} & L_{c_2} & \vdots & \vdots \\ 
-1 & L_{c_2} & \cdots & \cdots \\ 
-1 & L_{c_2} & \cdots & \cdots \\
\end{pmatrix}
\]

\[
B = \begin{pmatrix} B_L \mid B_U \end{pmatrix}
\]

\[
\max_{u,v} \quad s_0 = u^T Y_0
\]

s.t.

\[
v^T X_0 = 1
\]

\[
u^T Y - v^T X \leq 0
\]

\[
u^T B \leq 0
\]

\[
u^T \geq \varepsilon \cdot \mathbf{1}
\]

\[
v^T \geq \varepsilon \cdot \mathbf{1}
\]
Hierarchical BSC structure/Cascading objectives

- A node represents a card
- The leaves are the measures
- In brackets: lower – upper bounds
Necessary and sufficient conditions for feasibility

\[
\begin{align*}
\text{Li} & \geq 0 \\
\text{Ui} & \leq 1 \\
\text{Li} & \leq \text{Ui}
\end{align*}
\]

Pure DEA

Feasible
Non feasible
DEA-BSC: Example 1

**Figure 1**: Two-dimensional expected output including 51 enveloping projects

**Figure 2**: Scores attained by the DEA-BSC model for the enveloping projects on curve a for two sets of balancing limits
DEA-BSC: Example 2

**Figure 1**: Two-dimensional expected output including 16 sub-efficient projects

**Figure 2**: Scores attained by the DEA-BSC model for the enveloping projects on *curve b* for three sets of balancing limits
Summary and conclusion

- We employ a multi-criteria approach for R&D project evaluation
- We combined concepts taken from DEA and BSC, which have proven to be useful measurement and analysis tools
- These concepts were integrated into a single DEA-BSC model
- The model discriminates projects according to desired characteristics, and ranks them in a manner which is consistent with the organizational focus