Research Collaboration Workshop:

Optimization and Uncertainty Quantification in Energy and Industrial Applications

Intuition and Analytics in Business Decision Making

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AGENDA

Background
- intuition, analytics
- with a focus on business decisions

The Problem
- intuition VS analytics
- including insights from Simon & Kahneman

Approaches to Solution
- intuition AND analytics
- including 3 techniques used at Intel
BIG DECISIONS

~200,000 BC

- Mastery of fire
- Domestication of animals
- Cultivation of plants

15,000 BC

- Industrial Revolution 1
- Standard Oil (1870)
- General Electric (1892)
- US Steel (1901) ($1.4B)

1750-1850 AD

- Industrial Revolution 2

1850-1900 AD

- GM ($10B), Exxon ($6B)
- US Steel ($3B), GE ($3B)

1955 AD

- GM ($10B), Exxon ($6B)
- US Steel ($3B), GE ($3B)

2016 AD

- SINOPEC ($486B)
THE RISE OF INTUITION

~200,000 BC

Intuition = the sum of our life experience applied to the situation at hand.

Standard Oil (1870)
General Electric (1892)
US Steel (1901) ($1.4B)
GM ($10B), Exxon ($6B)
US Steel ($3B), GE ($3B)

SINOPEC ($486B)

1955 AD
2016 AD
THE RISE OF INTUITION

~200,000 BC

Reliable Intuition = \( f(\text{structure, feedback, repetition}) \)

Standard Oil (1870)
General Electric (1892)
US Steel (1901) ($1.4B)
GM ($10B), Exxon ($6B)
US Steel ($3B), GE ($3B)

1955 AD

SINOPEC ($486B) 2016 AD
THE RISE OF ANALYTICS

~200,000 BC

INTUITION

Standard Oil (1870)
General Electric (1892)
US Steel (1901) ($1.4B)

GM ($10B), Exxon ($6B)
US Steel ($3B), GE ($3B)

1955 AD

SINOPEC ($486B)

Turing (1937)
Transistor (1947)
Integrated Circuit (1959)
Microprocessor (1971)
Adv. Search (1950’s)
Math Prog. (1957)

2016 AD
THE PUNCHLINE

~200,000 BC

INTUITION

BIG BUSINESS DECISIONS

ANALYTICS

1870 AD

1955 AD

2016 AD
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PERFECT RATIONALITY

Expected Utility Hypothesis / Diminishing Marginal Utility

- Nicholas Bernoulli (1713) poses the St. Petersburg Paradox
- Gabriel Cramer (1728) and Daniel Bernoulli (1738) propose solutions
  - Gossen (1854), Jevons (1871), Menger (1872), Walrus (1874)

**Humans have perfect rationality**

- always act in a way that maximizes their utility
- capable of arbitrarily complex deductions towards that end
- capable of thinking through all possible outcomes
- always choose the course that will result in the best possible outcome
BOUNDDED RATIONALITY

Human decision makers have to work under unavoidable constraints:

- Difficult to collect all data and information, much of which is unreliable.
- Difficult to generate all possible alternatives and their consequences.
  - Limited capacity to compute (wetware or hardware).
  - Limited amount of time available to make a decision.

Herbert Simon: 1978 Nobel Memorial Prize in Economics
"for his pioneering research into the decision-making process within economic organizations"

1982 book 'Models Of Bounded Rationality'

Humans have bounded rationality.

They make satisficing (not maximizing) choices in complex situations.
BIASED RATIONALITY

Anchoring and adjustment, Attribute substitution, Availability heuristic
Base rate fallacy, Conjunction fallacy, Loss aversion, Optimism bias
Planning fallacy, Preference reversal, Status quo bias, ...
Prospect Theory, Cumulative Prospect Theory

Daniel Kahneman : 2002 Nobel Memorial Prize in Economics
"for having integrated insights from psychological research into
economic science, especially concerning human judgment
and decision-making under uncertainty"

2013 book ‘Thinking, Fast and Slow’

Humans have biased bounded rationality.
They bring a large set of interacting biases to every situation.
"Overconfident professionals sincerely believe they have expertise, act as experts and look like experts. You will have to struggle to remind yourself that they may be in the grip of an illusion."

Daniel Kahneman

Human decision makers, 
ESPECIALLY THOSE WITH A ‘TRACK RECORD’ OF (ACCIDENTAL) SUCCESS, are irrationally overconfident in their bounded biased decision making intuitions.
IMPORTANT BUT UNANSWERED QUESTIONS

How bad are we?

What can we do about it?
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Approaches to Solution
- intuition AND analytics
- including 3 techniques used at Intel
1) Over-riding Intuition
   - Estimating how bad we are

2) Implicitly using Intuition
   - Experiments in what can we do to improve

3) Explicitly using Intuition
   - Latest experiments

Conclusions
APPROACHES TO SOLUTION

1) Over-riding Intuition
   - Estimating how bad we are

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Conclusions
SIZING FACTORY EQUIPMENT

- Given the flow of the manufacturing process,
- The properties of the equipment,
- The production goals of the new factory,
- Decide how many instances of each equipment type to purchase to realize the goal at minimal cost.

- Considering re-entrant flow and integer buys …
- Intuition = Divide and Conquer

- Team A:
  \[ #A = f(#\text{steps}_A, \text{run rate}_A, \text{MTF}_A, \text{MTR}_A, \ldots) \]

- Team B:
  \[ #B = f(#\text{steps}_B, \text{run rate}_B, \text{MTF}_B, \text{MTR}_B, \ldots) \]

- Team C:
  
  …..

The result was spending $X$ (where $X$ is a big number) to hit $Y\%$ of the production goal (where $Y$ is less than 100).
SIZING FACTORY EQUIPMENT

- Although the machines appear to all be independent, variability is transmitted along the manufacturing line through material flow ...

- Build and validate a discrete event simulation
- Use the results to order equipment from highest to lowest utilization
- Buy more of the highly utilized equipment
- Buy less equipment that shows low utilization
- Re-simulate until factory output hits goal

- Ave. Result: achieve goal at 15% less cost.
HOW BAD ARE WE ??

Although we still study the decision process in detail before we commit …

- how is it solved now (watch them do it)?
- what data is available (look at it yourself)?
- how is the solution evaluated (success)?
- ……

We are usually very happy to commit to …

- cutting time in half (thinking we will get 5x-10x)
  (always clarifying data time vs. decision time)
- improving the solution by 5% (thinking 10%-15%)
  (always clarifying incremental improvement)
1) Over-riding Intuition
   - Estimating how bad we are

2) Implicitly using Intuition
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Conclusions
• A group of experts have a distribution of biases 
• Gather forecasts independently from a large group of experts 
• Aggregate the forecasts 
• Perhaps the biases will cancel and produce an accurate forecast 
• We have a large set of customers 
• They are “experts” in the electronics business 
• When we achieve a design win we get their forecasts
Correlation of DW and Billings

Actual Billing Volumes

DW Forecasted Volumes

\[ R^2 = 0.7258 \]
Cumulative Billings and Cumulative DW Model

Volumes (units)

Weeks Since Introduction

Billings
(Cumul)

DW Model
(Cumul)
Mean Absolute Percent Error (MAPE)

- new method
- old method

Products P1 through P9 and Overall Average
APPROACHES TO SOLUTION

1) Over-riding Intuition
   - Estimating how bad we are

2) Implicitly using Intuition
   - Experiments in what can we do to improve

3) Explicitly using Intuition
   - Latest experiments

Conclusions
Project Portfolio Management
The Business Problem

- There are products the company wants to launch over time.
- Each product requires multiple substantial engineering projects.
- The projects all cost something.
- The products all bring a benefit to the company.
- The projects are interrelated in a variety of ways.

- There is not enough budget to fund all the projects!
- How should the budget be allocated to maximize benefit?
- How can various qualitative & quantitative criteria be included?
- What portfolio of engineering projects should be funded?
At a scale relevant to INTEL Corporation ...

- the problem is too complex to solve well with business intuition ...
- there are more business details than can be analytically modelled ...

The solution process must include:

- analytics informing intuition
- intuition informing analytics
MAPPING: Entities, Interactions and Values

- TAM
- SAM
- VOL
- NPV
- Mfg.
- Cost
- DATA
- Eng.
- Cost
- Project-a
- Project-b
- Project-c
- Project-d
- Project-x
- Project-y
- Project-z

required
optional
Influence
AND, ORs, SEQ

projects impacting markets
projects impacting platforms
projects impacting silicon

DECISION ENGINEERING
MAPPING: Entities, Interactions and Values

- **TAM**
- **SAM**
- **VOL**
- **ASP**
- **NPV**
- **Mfg. Cost**
- **DATA**
- **Eng. Cost**

Projects impacting markets:
- Project-a
- Project-b
- Project-c
- Project-y
- Project-x
- Project-d
- Project-z

Projects impacting platforms:

Projects impacting silicon:

Prospects 1,2,3

MAPPING: Entities, Interactions and Values

- **required**
- **optional**
- **Influence**
- **AND, ORs, SEQ**

**NPV**

**TAM**

**SAM**

**VOL**

**ASP**

**Mfg. Cost**

**DATA**

**Eng. Cost**

DECISION ENGINEERING
MAPPING: Entities, Interactions and Values

- TAM
- SAM
- VOL
- ASP
- NPV
- Mfg. Cost
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- Eng. Cost

Influence AND, ORs, SEQ

- Project-a
  - projects impacting markets
- Project-b
  - projects impacting platforms
- Project-c
  - projects impacting silicon
- Project-d
- Project-x
- Project-y
- Project-z
An Ordered Set of Non-Dominated Portfolios

Efficient Frontier of non-dominated portfolios
THE BUSINESS PROCESS
Analytics ↔ Intuition using “Elimination by Aspects”

**Essential to:** Allow the intuition to inform the analytics.

**Difficult Because:** Challenging to align qualitative and strategic objectives with quantitative objectives.

**Our Current Solution:** “Elimination by Aspects” allows the combination of many objectives to narrow the generated feasible set to a few desirable portfolios.

*Supports decision maker in feeling satisfied with their final choice of a portfolio.*
Using the **Budget** Aspect

- **Check Portfolios wrt Budget**
- Portfolio spend within +/- 10% of budget
Efficient Frontier of non-dominated portfolios

Strong portfolios within +/- 10% of the budget …

… checked over (multiple) year budget.
Using the **Strategy** Aspect

- **Check Products wrt Strategy**
  - Force selected products in / out and re-optimize

- **Check Portfolios wrt Budget**
  - Portfolio spend within +/- 10% of budget
Using the **Strategy Aspect**

- **Efficient Frontier of non-dominated portfolios**
- **Portfolio Spend (next year)**
- **Portfolio NPV**

**Projects/Products that are in ** **ALL** of the portfolios selected**

**Projects/Products that are in ** **SOME** of the portfolios selected**

**Projects/Products that are in ** **NONE** of the portfolios selected**

**Force OUT ??**

**Force IN ??**

**Drill Down, Decide !!**

**DECISION ENGINEERING**
**PRODUCT ROADMAP**

What products are in (colored) and out (grey) of the portfolio under inspection.

<table>
<thead>
<tr>
<th>ROADMAP</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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Using the **Resources** Aspect

- **Budget**:
  - 20 portfolios

- **Strategy**:
  - 14

- **Resources**:
  - 8

- **Check Portfolios wrt Budget**
  - Portfolio spend within +/- 10% of budget

- **Check Products wrt Strategy**
  - Force selected products in / out and re-optimize

- **Check Skill Set Changes**
  - Consider the suggested skill changes over time

DECISION ENGINEERING
Using the **Resources** Aspect

<table>
<thead>
<tr>
<th>TIME</th>
<th>NUMBER REQUIRED</th>
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<tbody>
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<table>
<thead>
<tr>
<th>SKILL SET</th>
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<tbody>
<tr>
<td>cpu</td>
</tr>
<tr>
<td>memory</td>
</tr>
<tr>
<td>bios</td>
</tr>
<tr>
<td>network</td>
</tr>
<tr>
<td>disk</td>
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<tr>
<td>cache</td>
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<tr>
<td>os</td>
</tr>
</tbody>
</table>
Using the **Balance** Aspect

- **Budget**
  - Check Portfolios wrt Budget
    - Portfolio spend within +/- 10% of budget

- **Strategy**
  - Check Products wrt Strategy
    - Force selected products in / out and re-optimize

- **Resources**
  - Check Skill Set Changes
    - Consider the suggested skill changes over time

- **Balance**
  - Check Balance across Markets
    - Consider budget allocation and return in all business segments
Using the **Balance** Aspect

**Branches** as business segments (enterprise, workstations, high performance, cloud, etc.)

**Leaves** as ...
- Projects sized as dollar budget
- Projects sized as headcount
- Products sized by NPV
- Products sized by volume

**Colors** as ...
- Projects in flight, new projects, strategic projects (forced in)
- Investment Efficiency (prod. NPV/proj. SPEND)
- Year a product enters market
Using the **Special Aspect**

- **Senior Management Intuition**
  Special knowledge from Sales & Marketing, Product Design, etc

- **Check Balance across Markets**
  Consider budget allocation and return in all business segments

- **Check Skill Set Changes**
  Consider the suggested skill changes over time

- **Check Products wrt Strategy**
  Force selected products in / out and re-optimize

- **Check Portfolios wrt Budget**
  Portfolio spend within +/- 10% of budget

- **Check Products wrt Strategy**
  Force selected products in / out and re-optimize

**DECISION ENGINEERING**
CONCLUSIONS

Business decision makers are irrationally overconfident in their bounded biased decision making intuitions.

Application of analytics, to exclude or employ intuition, can yield faster better decisions.

Analytics guiding intuition AND Intuition guiding analytics looks most promising … BUT …
IT’S NOT JUST WHAT WE MAKE.

IT’S WHAT WE MAKE POSSIBLE.

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