# GAME THEORY AND BEHAVIORAL EXPERIMENTATION IN ENGINEERING SYSTEMS DESIGN

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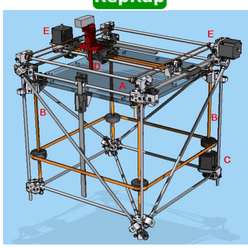
# Social Design and Manufacturing

**Individuals as contributors**



**Individuals as problem solvers**

Open-source

Crowdsourcing

Social Design & Manufacturing

Maker Communities

**Individuals as makers**

# Background of Crowdsourcing

***Crowdsourcing:*** the practice of outsourcing tasks, traditionally performed by employees or suppliers, to a large group of people in the form of open tournaments. *[J. Howe, 2008]*

How should we design effective crowdsourcing initiatives for *engineering design*?

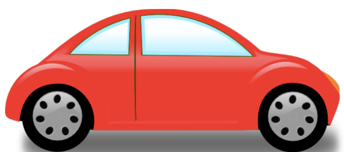
Fast Adaptable Next-Generation Ground Vehicle (FANG GCV) *[DARPA, 2010]*

# Analysis Framework for Design Crowdsourcing

**Game theory** ⟵ Validation ⟵ **Behavioral Experimentation**

**What designers would do**

**A design task**



**Designer 1**

*Maximize* payoff ($\pi_1$)

*Non-cooperative game*

**Designer 2**

*Maximize* payoff ($\pi_2$)

Nash Equilibrium

**What designers actually do**

**HOW** do people deviate from the assumptions?

**WHY** do people deviate from the assumptions?

Refinement

Z. Sha, J. H. Panchal, " Behavioral Experimentation and Game Theory in Engineering Systems Design", *Journal of Mechanical Design*, Transactions of the ASME, volume 137, issue 5, pp: 051405 (10), 2015.

# Theoretical Framework

**1. Quality function:**

Effort, Knowledge

$$\underbrace{q_i = q_i(e_i, K_i)}$$

$$q_i = q_i(e_i, K_i)$$

**2. Contest success function:**

$$P_i = \begin{cases} \dfrac{f(q_i)}{\sum_{j=1}^{N} f(q_j)}, & if \sum_{j=1}^{N} f(q_j) > 0 \\ \dfrac{1}{2}, & otherwise \end{cases}$$

**3. Payoff function:**

$$E(\pi_i) = \Pi P_i - C_i$$

Expected payoff, Prize, Cost

**Rational Reaction Sets:**

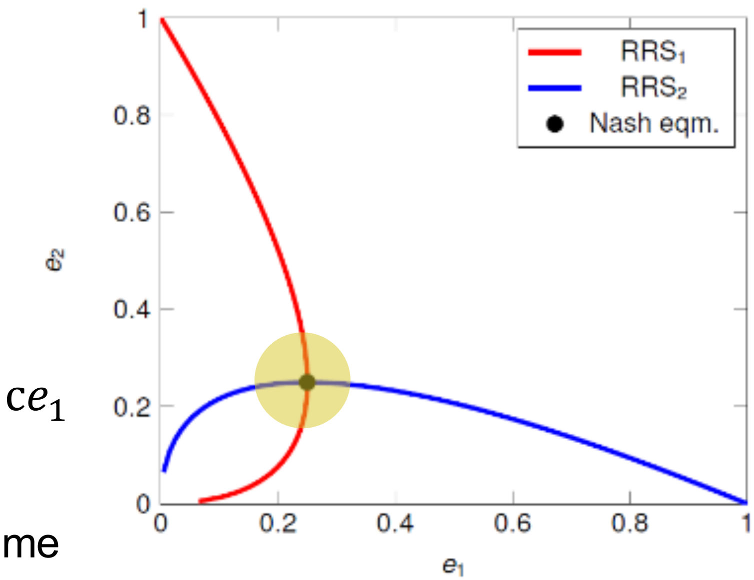
$$\begin{cases} E'(\pi_1) \\ E'(\pi_2) \end{cases}$$

# Options of Game Theoretic Models

**1. Linear-from quality:** $q_i = \alpha e_i$

**2. Power-from CSF:** $P_i = \dfrac{q_i^m}{\sum_{j=1}^{N}(q_j^m)}$

**3. Payoff function:** $E(\pi_i) = \Pi \underbrace{\left(\dfrac{e_i^{\mathrm{m}}}{e_1^{\mathrm{m}} + e_2^{\mathrm{m}}}\right)}_{\text{Two-player game}} - ce_1$

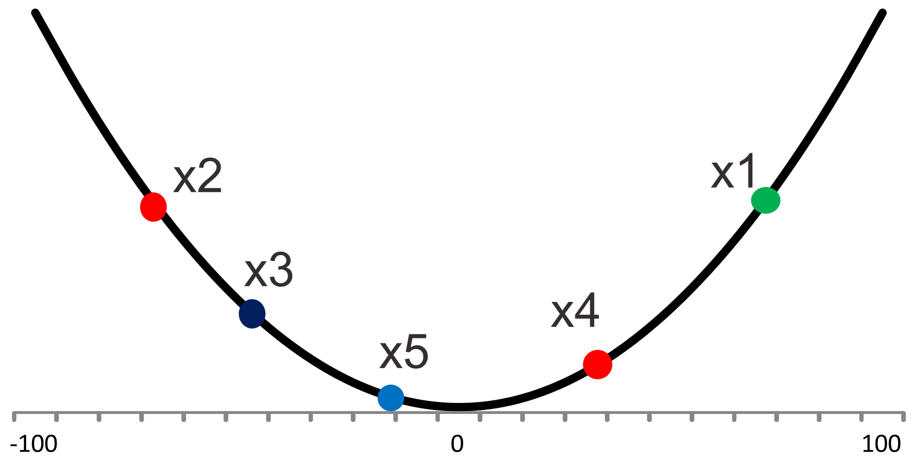



| CSFs \ QFs | Linear form $q_i = \alpha e_i$ | Exponential $q_i = \alpha exp(\beta e_i)$ |
|---|---|---|
| Power form $P_i = \dfrac{q_i^m}{\sum_{j=1}^{N}(q_j^m)}$ | Unique Nash Equilibrium $e_1 = e_2 = \dfrac{\Pi m}{4c}$ | Multiple Nash equilibrium |
| Logit form $P_i = \dfrac{exp(kq_i)}{\sum_{j=1}^{N}(exp(kq_i))}$ | Multiple Nash equilibrium | Unique Nash Equilibrium $e_1 = e_2 = \dfrac{1}{\beta}\ln\left(\dfrac{4c}{\prod k\alpha\beta}\right)$ |

# Characteristics of Design Problems

1. A designer's goal is to find the best design
2. Evaluate the performance of candidate designs
3. More experiments and better design quality
4. Experiments incur costs
5. The final design competes with other designs

# Function Optimization Game




Optimizing an unknown function

Rules:

1. Each sampling with a cost of 10 tokens for low cost setting, and 20 for high cost.

2. The amount of prize for winner is $\Pi = 200$ tokens

3. Paying rule: winner-takes-all & loser-takes-nothing

# Design of Experiment

- The ***experiment*** contains 4 sessions.
- 1 ***session*** consists of 2 treatments.
- 1 ***treatments*** has 15 ***periods***.

| Session No. | Cost in the first treatment | Cost in the second treatment | Number of participants |
|---|---|---|---|
| **1 (Low cost first)** | Low (LL) | High (LH) | 10 |
| **2 (High cost first)** | High (HH) | Low (HL) | 6 |
| **3 (High cost first)** | High (HH) | Low (HL) | 14 |
| **4 (Low cost first)** | Low (LL) | High (LH) | 14 |

(Low: 10 tokens; High: 20 tokens)

# Testable Hypothesis

***Hypothesis 1*****:** As the cost per trial increases, the expected number of tries decreases.

Decision-making preferences → Decision-making Behaviors

***Hypothesis 2:*** The solution quality monotonically increases with the number of tries.

Decision-making behaviors → Design quality

***Hypothesis 3:*** Increasing the number of tries increases the probability of winning.

Decision-making behaviors → Crowdsourcing performance

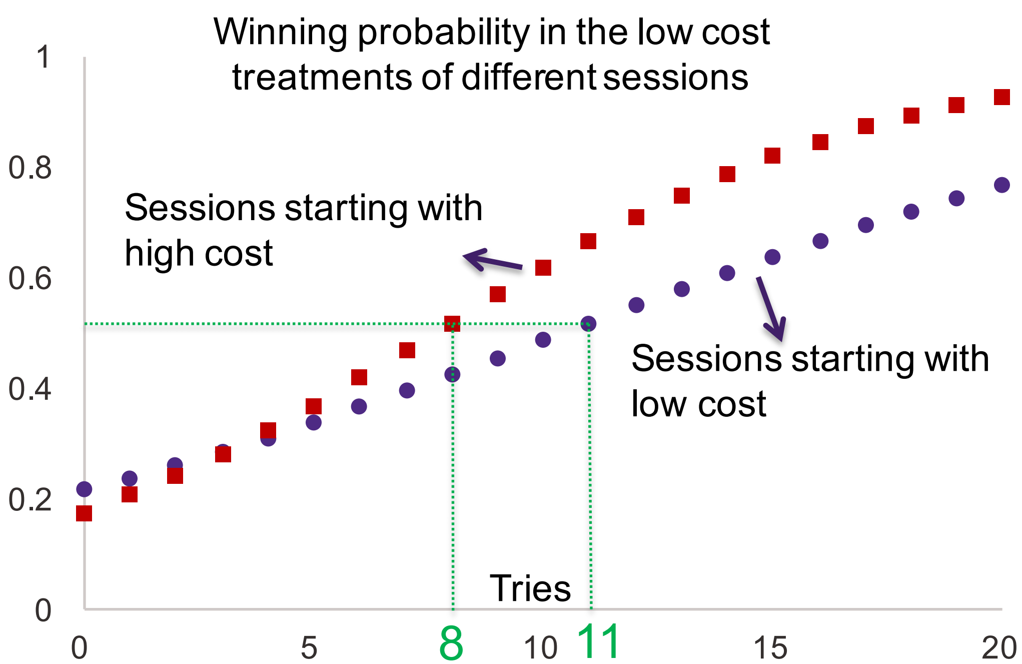
# Irrational Behavior

**Designers' Rational Behaviors**

Cost $(c)$ ⇨ Number of tries $(e)$ ⇨ Winning Probability $(P)$

⇩

Quality $(q)$




**Designers' Irrational Behaviors**

***Anchoring bias:***
Individuals use an initial piece of information to make subsequent judgements.
*[Tversky, A., and Kahneman, D., science, 1974]*

# Summary of Insights

1. ***Wining probability***: the combination of power form of CSF and exponential QF.

$$P(win = yes) = \frac{\exp(\beta me_1\ )}{\exp(\beta me_1\ ) + \exp(\beta me_2\ )} = \frac{q_1^m}{q_1^m + q_2^m}$$

2. ***Contest theory***: the finding of contest theory holds true in engineering system design.

3. ***Anchoring bias***: help save resources and enable designers to optimize the amount spent in creating the contest.

# Future Work

1. How to analytically model *the sequential decision-making* of designers under competition?

2. How other factors, such as *designers' expertise*, play a role in the decision-making under competition?

3. What if we use a *real design context*? Would that affect our results?

# Thank You!
# Questions?

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