Mental Mistakes Made by Systems Engineers While Creating Tradeoff Studies

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This file is located at http://www.sie.arizona.edu/sysengr/slides/
Wednesday 10:45 AM Track 2 Session 7

Reference

Smith, E. D., Son, Y. J., Piattelli-Palmarini, M. and Bahill, A. T., Ameliorating mental mistakes in tradeoff studies, *Systems Engineering,* **10**:3, 222-240, 2007.

All of the material in this presentation is based on original data or peer-reviewed journal papers. None of it comes from the Internet.

Our goal

- We want to help people create tradeoff studies to choose among alternatives.
- We want people to have confidence that they made the right decision.
- We recommend actions that will help people avoid making specific mental mistakes in doing tradeoff studies.
- Convince people to validate their systems
- Convince people to create PtItP.
- These recommendations are the prime deliverable of this research effort.

Components of a tradeoff study

- Problem statement
- Evaluation criteria
- Weights of importance
- Alternative solutions
- Evaluation data
- Scoring functions
- Normalized scores
- Combining functions
- Preferred alternatives
- Sensitivity analysis

The experimental procedure$_1$

- Over the past two decades, teams of students and practicing engineers in Bahill's Systems Engineering courses wrote the eight Wymorian system design documents for a particular system.
- This document set contains the problem statement and tradeoff studies.
- Each of these document sets took 100 man-hours to write and comprised 80 pages .
- We examined these project reports looking for 28 specific mental mistakes.
- We found multiple instances of a dozen of these mental mistakes.

The experimental procedure$_2$

- We present examples of the following mental mistakes
- Not Stating the Problem in Terms of Stakeholder Needs
- Vague Problem Statement
- Substituting a Related Attribute
- Dependent Criteria
- Forer Effect
- Weight of Importance Mistakes
- Anchoring and the Status Quo
- Equating Gains and Losses
- Not Using Scoring Functions
- Implying False Precision
- Obviating Expert Opinion
- Sensitivity Analysis Mistakes

How many?

- In Eric Smith's PhD dissertation he investigated seven dozen mental mistakes that could possibly affect tradeoff studies.
- In the paper by Smith et al. we explained 28 mental mistakes that actually did affect tradeoff studies.
- In this paper we present only a dozen, because we only examined the output of the process, and to document any of the others you would have to have been there during the discussions.

Mental Mistakes

- Emotions, cognitive illusions, conscious and unconscious biases, fallacies, fear of regret and the use of heuristics can cause mistakes in tradeoff studies.
- We will group all these terms under the phrase mental mistakes.
- The rest of this slide show lists specific mental mistakes and states how they can affect particular components of tradeoff studies.

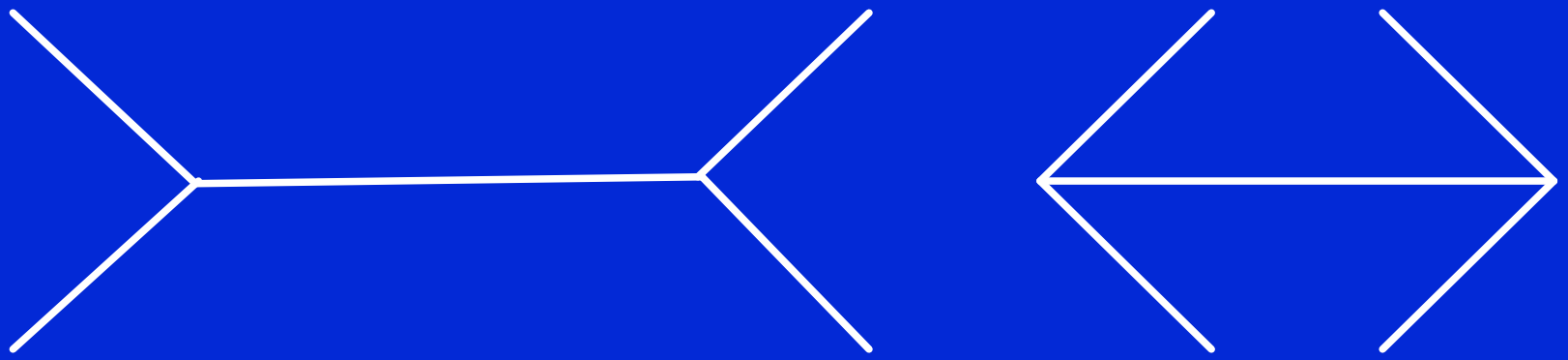
Humans are not rational*

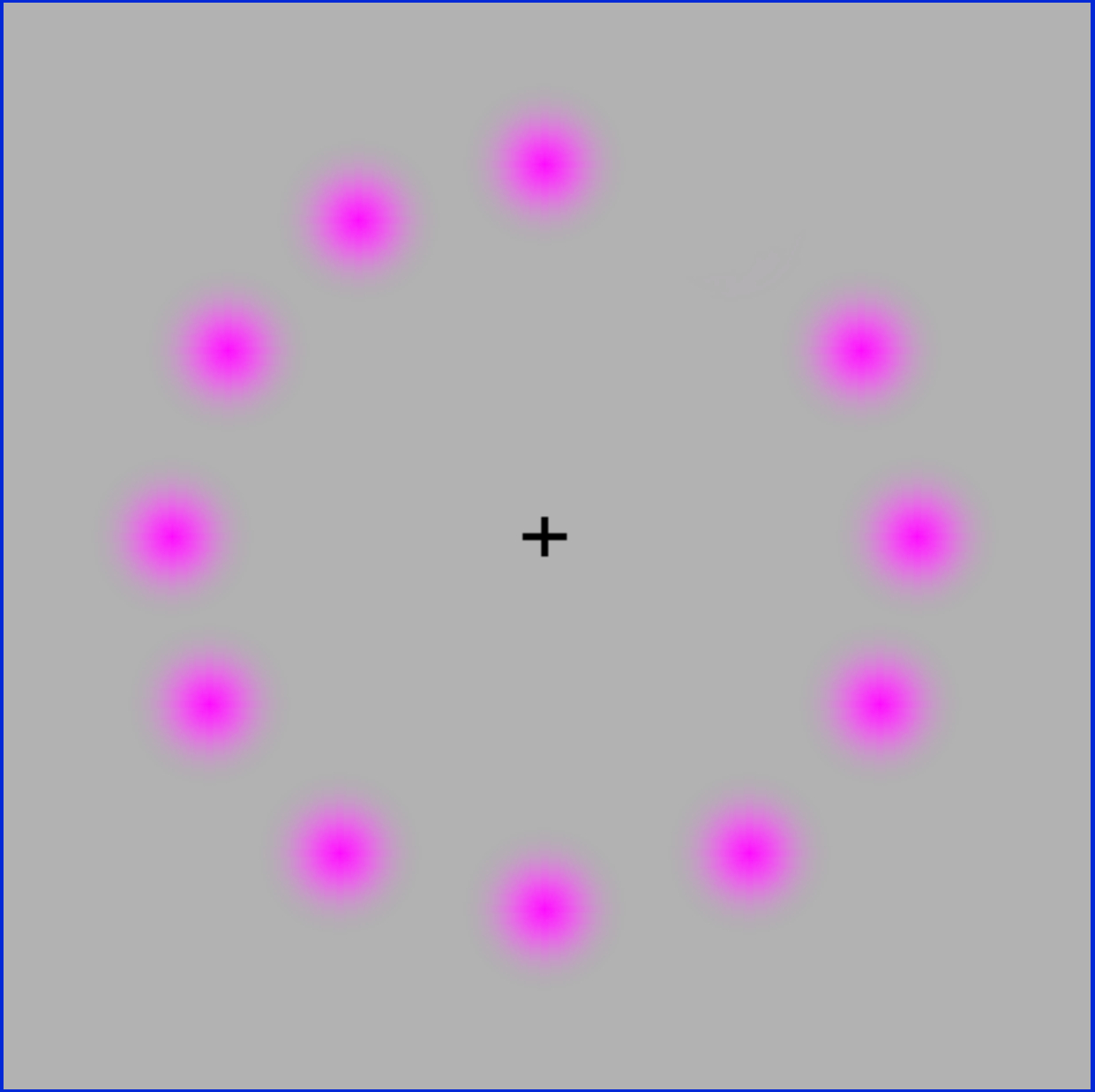
- Mark Twain said,
  - "It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so."
- Humans are often very certain of knowledge that is false.
  - What American city is directly north of Santiago Chile?
  - If you travel from Los Angeles to Reno Nevada, in what direction would you travel?
- Most humans think that there are more words that start with the letter r, than there are with r as the third letter.

Illusions*

- We call these cognitive illusions.
- We believe them with as much certainty as we believe optical illusions.

The Müller-Lyer Illusion*





Monty Hall Paradox$_1$*

Monty Hall Paradox$_2$*

Monty Hall Paradox$_3$*

Monty Hall Paradox$_4$*

Monty Hall Paradox$_5$*

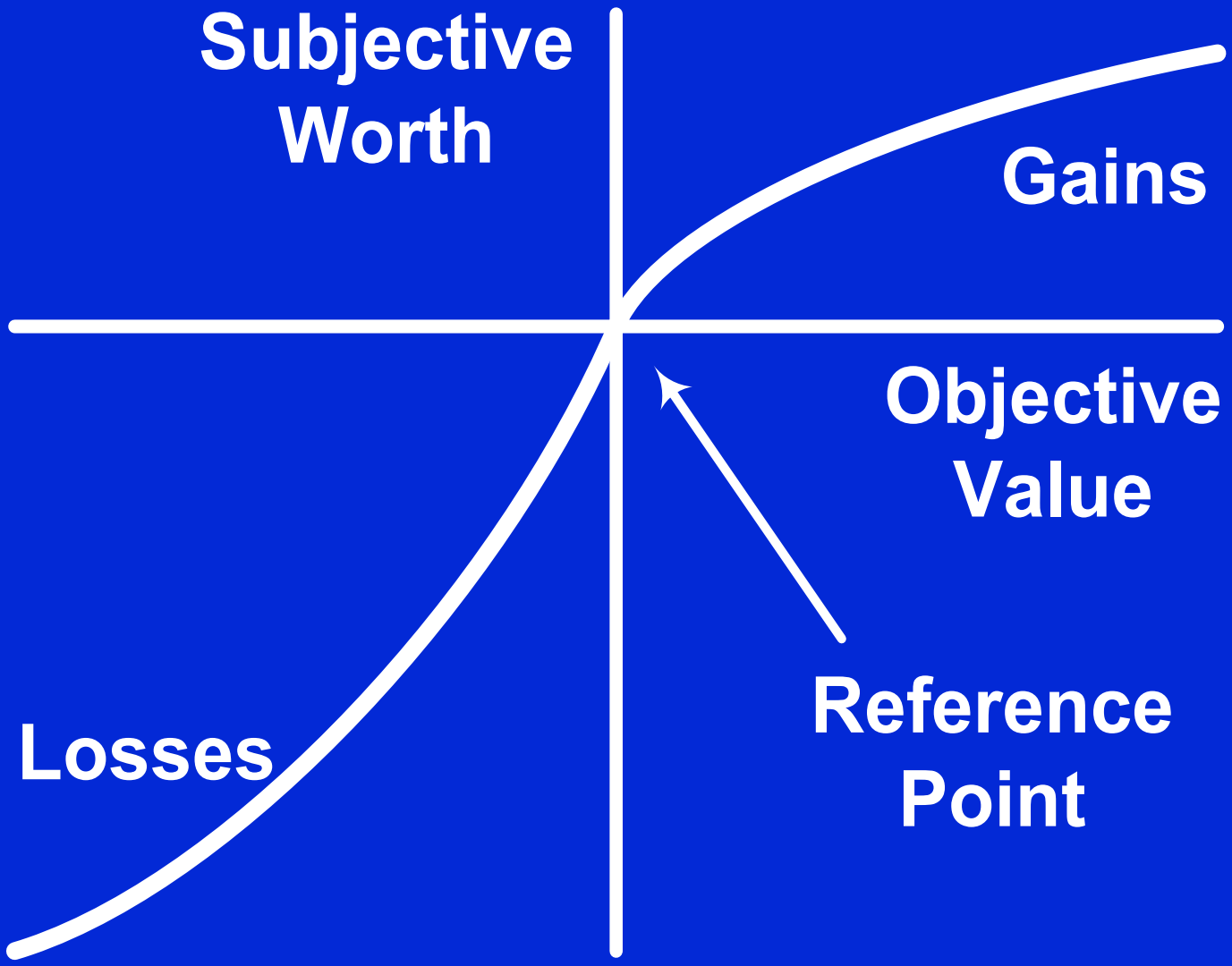
- Now here is your problem.
- Are you better off sticking to your original choice or switching?
- A lot of people say it makes no difference.
- There are two boxes and one contains a ten-dollar bill.
- Therefore, your chances of winning are 50/50.
- However, the laws of probability say that you should switch.

Monty Hall knew which door had the donkey

Monty Hall Paradox$_6$*

- The box you originally chose has, and always will have, a one-third probability of containing the ten-dollar bill.
- The other two, combined, have a two-thirds probability of containing the ten-dollar bill.
- But at the moment when I open the empty box, then the other one alone will have a two-thirds probability of containing the ten-dollar bill.
- Therefore, your best strategy is to *always* switch!

Gains and losses are not valued equally*



Humans are not rational$_2$

- Even if they had the knowledge and resources, people would not make rational decisions, because they do not evaluate utility rationally.
- Most people would be more concerned with a large potential loss than with a large potential gain. Losses are felt more strongly than equal gains.
- Which of these wagers would you prefer to take?*
  - $2 with probability of 0.5 and $0 with probability 0.5
  - $1 with probability of 0.99 and $1,000,000 with probability 0.00000001
  - $3 with probability of 0.999999 and -$1,999,997 with probability 0.000001

Humans are not rational$_3$

$2 with probability of 0.5 or $0 with probability 0.5

$0

Humans are not rational$_4$

$1 with probability of 0.99

$1,000,000 with probability 0.00000001

Humans are not rational$_5$

-$1,999,997 with probability 0.000001

You owe me two million dollars!

$3 with probability of 0.999999

Humans are not rational$_6$

- Which of these wagers would you prefer to take?
  - $2 with probability of 0.5 or
    $0 with probability 0.5
  - $1 with probability of 0.99 or
    $1,000,000 with probability 0.00000001
  - $3 with probability of 0.999999 or
    -$1,999,997 with probability 0.000001
- Most engineers prefer the $2 bet
- Very few people choose the $3 bet

- All three have an expected value of $1

How does this affect tradeoff studies?

- OK, so now we know that humans are bad decision makers.
- Their brains fool them.
- Humans make mental mistakes.
- Humans judge probabilities poorly.
- Now back to our specific topic,

What kinds of mistakes do systems engineers make when doing tradeoff studies?

Problem Statement Mistakes

- Bad problem stating
- Not stating the problem in terms of stakeholder needs
- Vague problem statement
- Attribute substitution

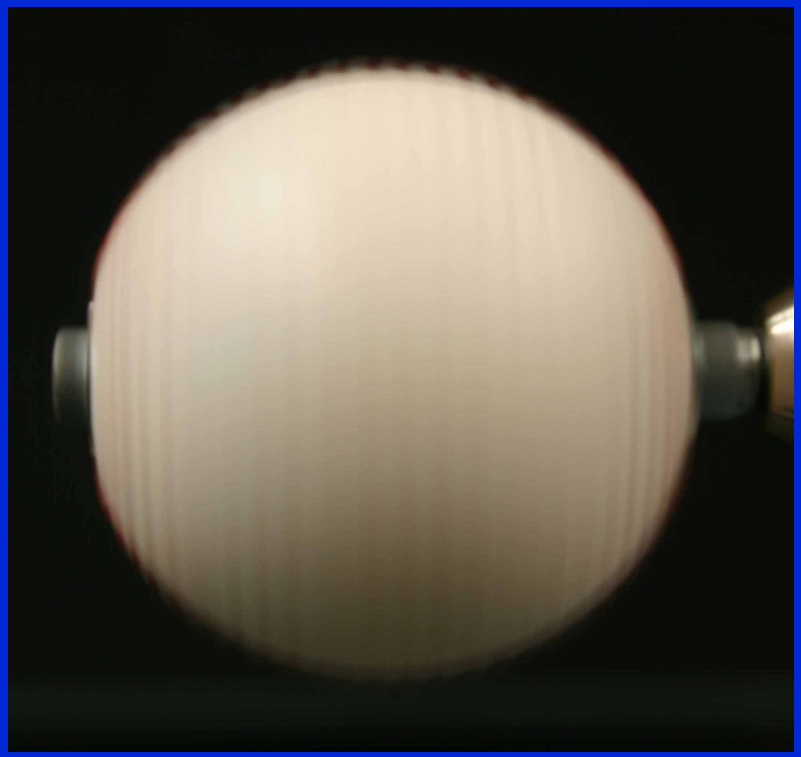
Bad problem stating^

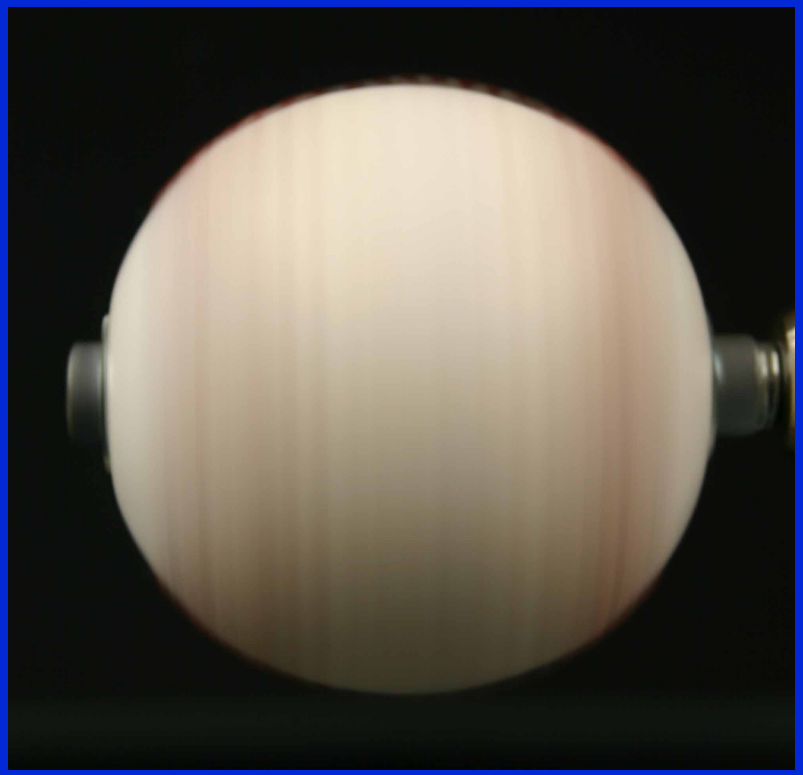
- "The problem of the design of a system must be stated strictly in terms of its requirements, not in terms of a solution or a class of solutions."

  Wayne Wymore
- It is a mistake to state the problem in terms of a solution instead of stakeholder needs and expectations.
- Recommendation: Communicate with and question the stakeholders in order to determine their values and needs.

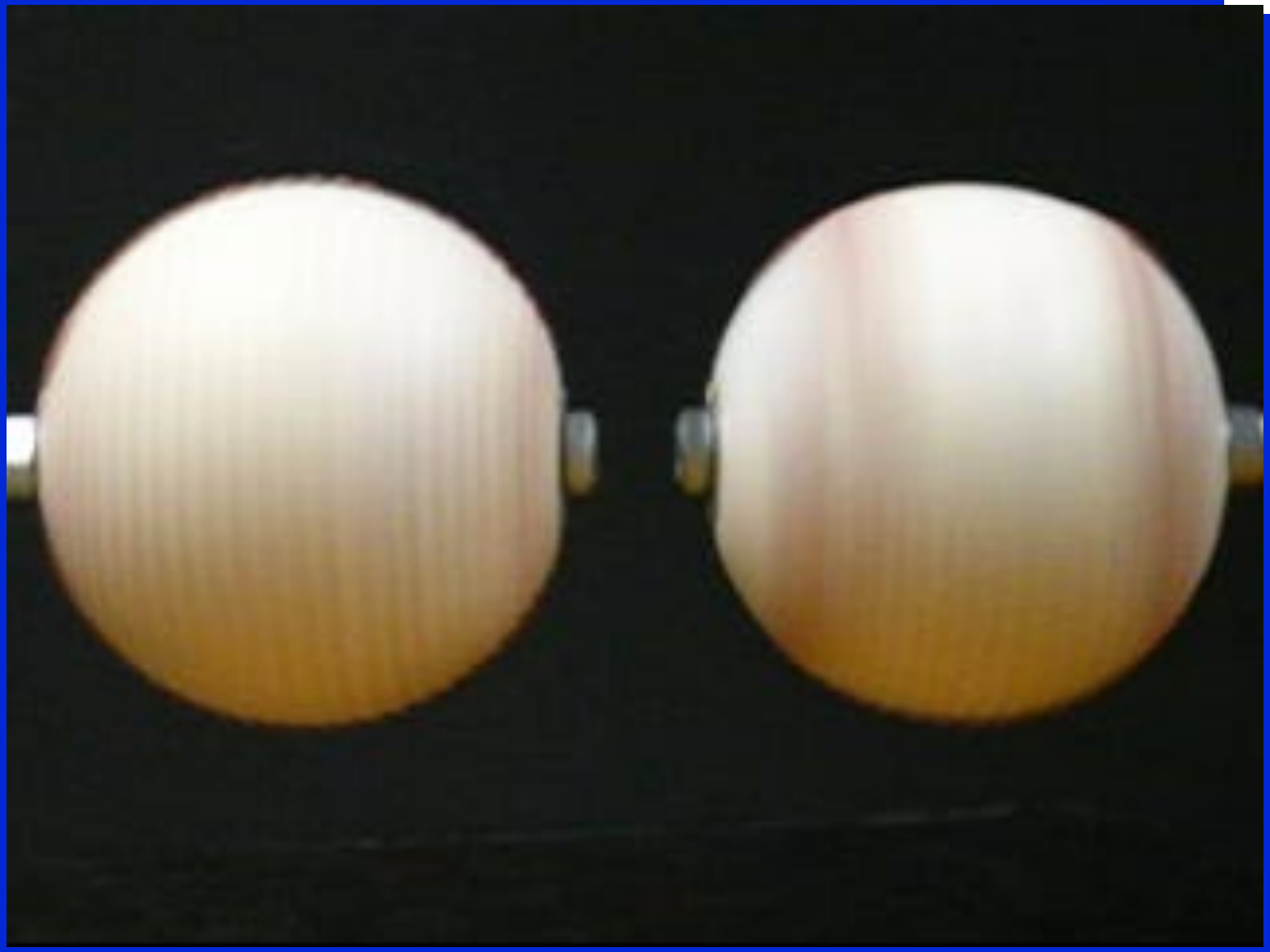
The Spin Coach Equipment

4-seam & 2-seam simulated fastballs

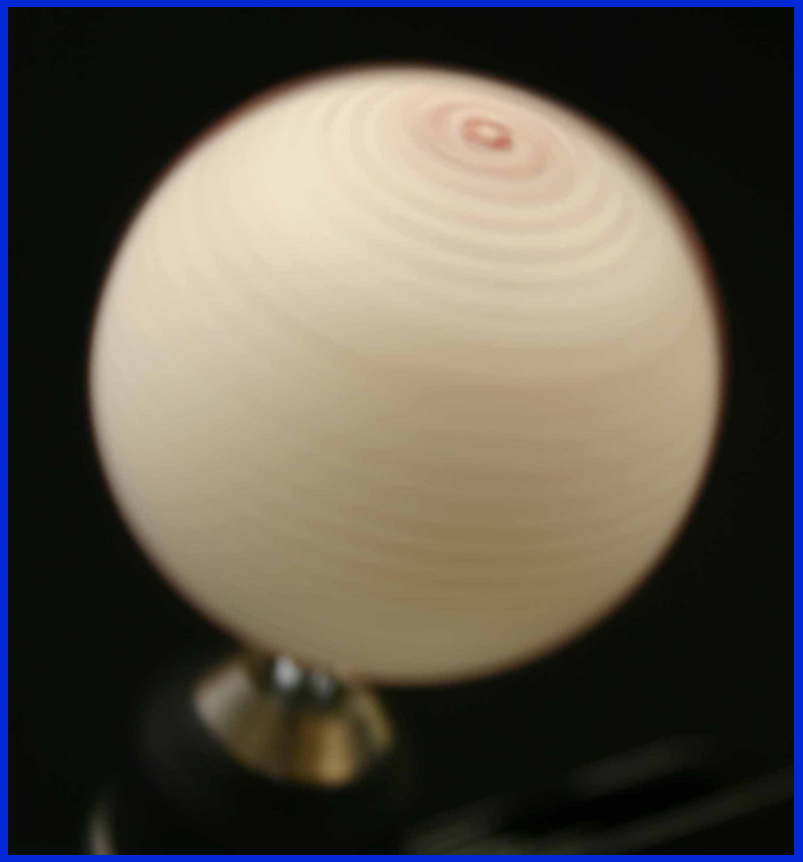


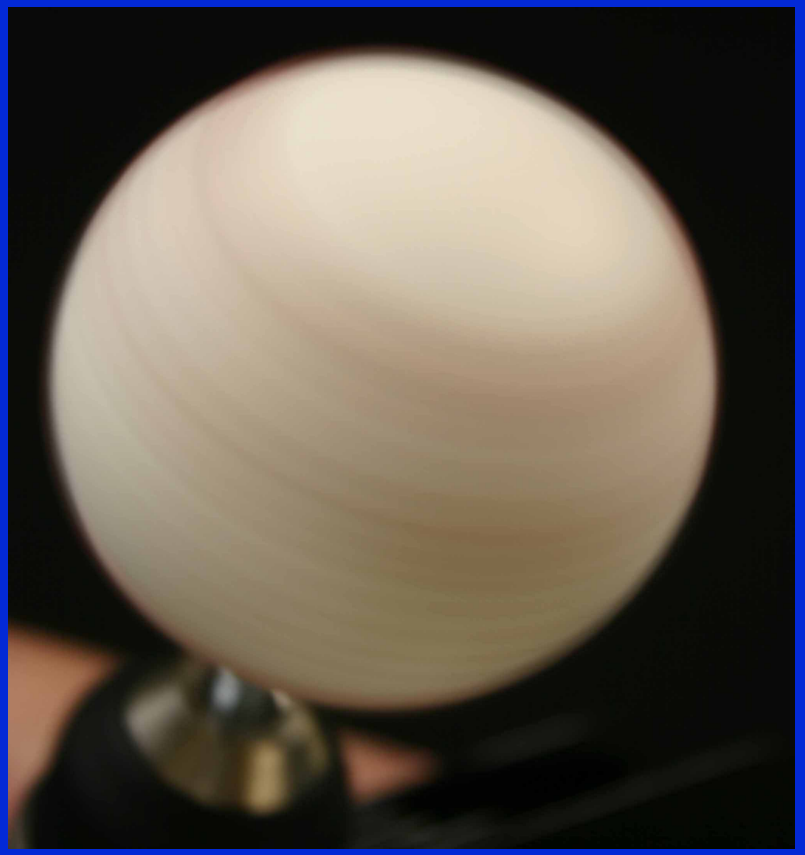


4-seam & 2-seam simulated fastballs

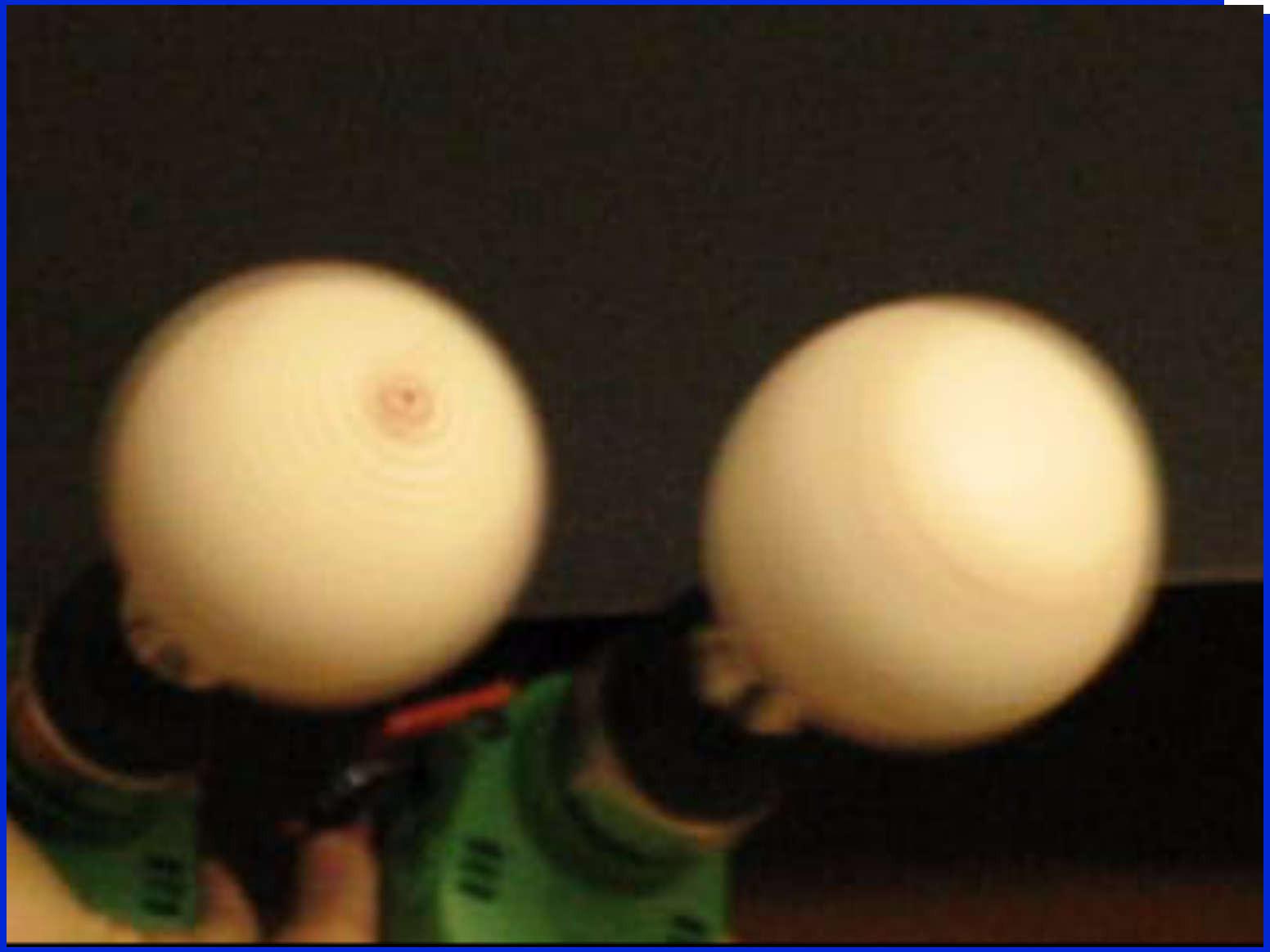


4-seam and 2-seam simulated sliders





4-seam and 2-seam simulated sliders



Not stating the problem in terms of stakeholder needs

Team excerpt: A video game trainer could also be used, in which a batter tries to gauge the spin on a video ball and predict where it would end up. This option could be implemented with a CD-ROM. The CD would go through the process of how to see the spin based on video taken from a laboratory. Dr. Terry Bahill, a professor in the Systems and Industrial Engineering (SIE) department at the University of Arizona, has set up a laboratory with equipment to simulate pitches with different types of spins. This laboratory would be a valuable resource in designing experiments to train a player to pick up the spin on a ball.

Actual quotes from team documents are set in the Garamond font.

Explanation of mistake

- This problem statement does not describe the batter's needs in terms of the system they were designing. If they were designing a different system, then the excerpt might be useful. But they were supposed to be designing a system to help the batter learn the spin-induced deflection of the ball.
- Suggested rewrite: Baseball and softball players need to learn how to recognize the spin of a pitched ball and use it to predict the spin-induced deflection of the ball.

Vague problem statement

- Team Excerpt: The differences in (baseball) spin result in visually detectable differences in the appearance of the spinning ball as it approaches the batter. Currently, players practice the assessment of spin and trajectory prediction during actual game play and team practice sessions. This process requires coordination between multiple players, and the use of a pitcher capable of delivering a repeatable baseball pitch to the batter.
- Suggested rewrite: For the baseball batter who needs to predict the trajectory of the pitch, the Spin Coach is a training system that helps him to recognize the spin on the pitch and predict the ball's spin-induced movement; unlike present coaches and books, the Spin Coach shows the batter how each pitch spins and helps him to recognize this spin.

Attribute substitution

- Team Excerpt: Use Case 2
- Name: Learn Spin-induced Deflections
- Iteration: 2.3
- Derived from: Concept of operations
- Brief description: Player uses the Spin Coach and learns to predict the spin-induced deflection of a ball.
- Added value: Player will be better able to predict the trajectory of the ball and consequently should have a higher batting average.
-
- Second Team Excerpt: 5.2.1.2 Effectiveness
- The measurement of effectiveness determines the percent increase on the user's batting average over time.

Explanation of mistake

- The Spin Coach is supposed to teach batters to predict the spin-induced deflection of the baseball, but as a measure of success these teams proposed to use the player's batting average.
- Suggested rewrite: We need to know, "Does training with the Spin Coach teach batters to predict the spin-induced deflection of the baseball?" But this is too hard to measure; therefore we substitute the player's batting average as a measure of success.
- Attribute substitution is a really tricky mistake, because everyone does it. We are doing it here, but we *do* tell our readers that we are doing this.

Evaluation Criteria Mistakes

- Dependent criteria
- Forer effect

Dependent criteria*

- Evaluation criteria should be independent.^
- For evaluating humans, Height and Weight are not independent: Sex (male versus female) and Intelligence Quotient are independent.
- Recommendation: Dependent criteria should be grouped together as subcriteria.

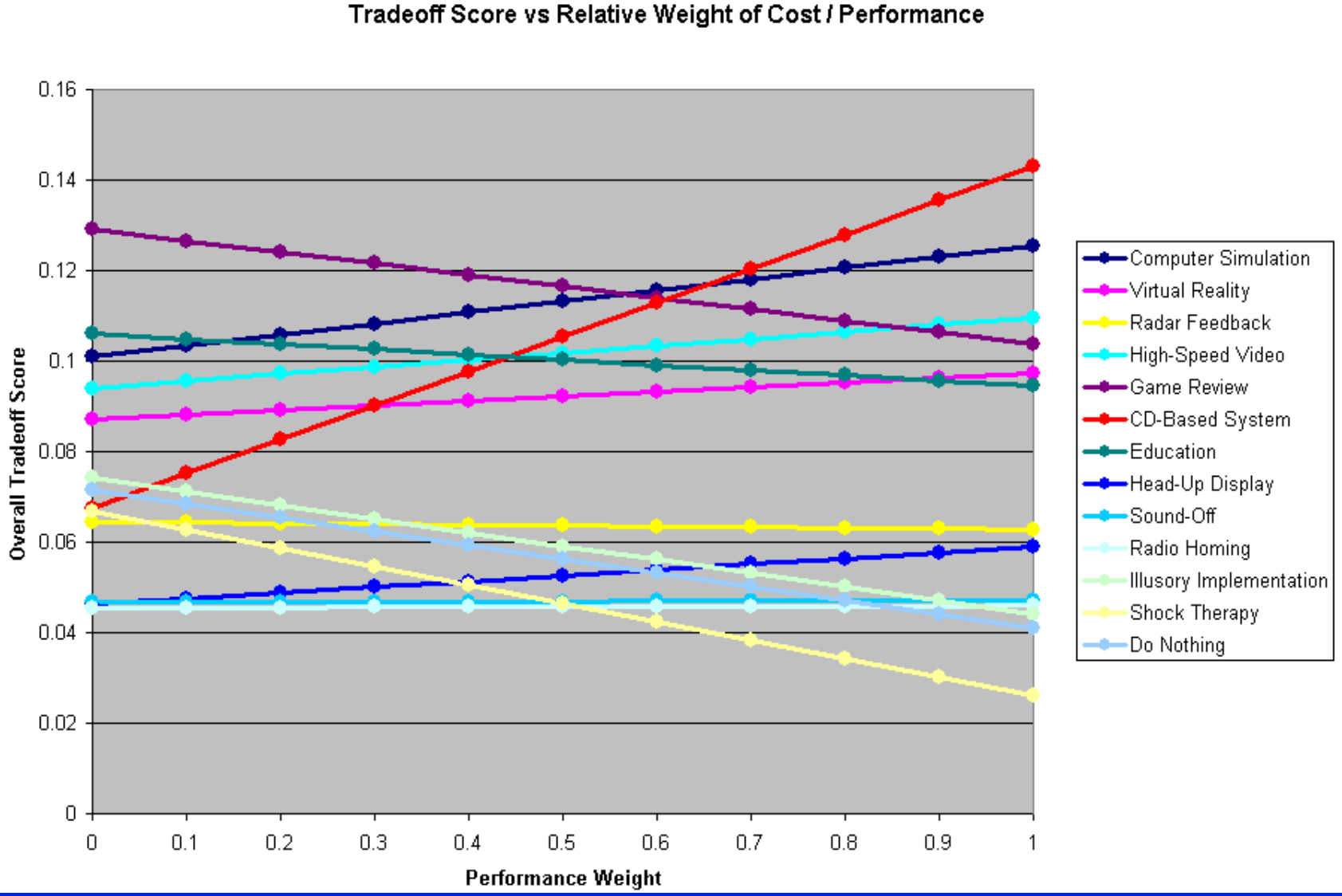
Dependent criteria

- Team Excerpt: The maximum current drawn by the system shall not exceed 15 amperes.
- The system shall operate on 120 volt, 60 hertz electricity.
- The system shall not consume more than 1.8 kilowatts.
- Suggested rewrite: The maximum current drawn by the system shall not exceed 15 amperes.
- The system shall operate on 120 volt, 60 hertz electricity.

Forer effect

- The analyst might fail to question or re-write criteria from a legacy tradeoff study that originated from a *perceived authority* and is now seemingly adaptable to the tradeoff at hand.
- Recommendations:
  - Give some time to considering and formulating criteria from scratch, before consulting and possibly reusing previously written criteria.
  - Generic criteria taken from the company process assets library must be tailored for the project at hand.

Forer effect



The only parameter being varied here is the relative weight of performance versus cost.

Explanation of mistake

- The textbook had a primitive sensitivity analysis that only considered one parameter, the tradeoff between cost and performance.
- We had a lecture and a homework that showed how to take partial derivatives and form semirelative sensitivity functions for each parameter in the tradeoff study.
- Despite warnings about its inadequacy, the teams repeatedly copied the method of conducting a sensitivity analysis from the legacy tradeoff study in the book. This was an example of the Forer effect. Students failed to question a sensitivity analysis that was presented by a perceived authority and was seemingly adaptable to their own tradeoff study.

Weight of Importance Mistakes

Weight of importance mistakes

Umpire's Assistant Team Excerpt		
Utilization of Resources Figures of Merit Requirements	Value	Normalized weight
1. Available Money	2	0.02326
2. Available Time	2	0.02326
2.1 System design & prototyping by 12/31/05	2	0.02326
2.2 System verification testing by 2/06	2	0.02326
3. Technological Restrictions	10	0.11628
3.1 to not significantly alter the dynamics of baseball	9	0.10465
3.2 to comply with local, regional, state, federal laws	10	0.11628
3.3 to comply with FCC rules	10	0.11628
4. Adaptability	8	0.09302
4.1 to comply with Standards & Specifications of MLB	8	0.09302
4.2 to comply with Standards & Specifications of NCAA	8	0.09302

The normalized weights add up to 0.826. They should add up to 1.0 in each category and subcategory.

Suggested rewrite

Suggested rewrite for the Umpire's Assistant			
Utilization of Resources Evaluation Criteria	Weight of Importance	Criteria Norm. Weight	Sub criteria Norm. Weight
1. Available Money	2	0.09	
2. Available Time	2	0.09	
2.1 System design & prototyping by 12/31/05	2		0.5
2.2 System verification testing by 2/14/06	2		0.5
3. Technological Restrictions	10	0.45	
3.1 to not significantly alter baseball dynamics	9		0.31
3.2 to comply with local, state & federal laws	10		0.35
3.3 to comply with FCC rules	10		0.35
4. Adaptability	8	0.36	
4.1 to comply with MLB rules	8		0.5
4.2 to comply with NCAA rules	8		0.5

Anchoring and Status Quo Mistakes

Anchoring

- A person's first impression dominates all further thought.
- People were shown a wheel of fortune with numbers from one to hundred.
- The wheel was spun and the subjects were asked to estimate the number of African nations in the United Nations.
- If the wheel showed a small number, like 12, the subjects underestimated the correct number.
- If the wheel showed a large number, like 92, the subjects overestimated the correct number.
- Recommendation: When estimating values for parameters of scoring functions, think about the whole range of expected values for the parameters.

Anchoring$_2$

- The order in which the alternatives are listed has a big affect on the values that humans give for the evaluation data. Therefore, you should fill out a tradeoff study matrix row by row with the status quo as the first alternative. This will make the evaluation data for the status quo the anchors for estimating the evaluation data for the other alternatives. This means that the anchoring alternative is known, is consistent, and you have control over it.
- Recommendations:
  - Make the status quo the first alternative.
  - In one iteration examine the scores left to right and in the next iteration examine them right to left.

Anchoring and the status quo

Tradeoff matrix for alternative architectures of the Spin Coach						
	Alternatives					
Criteria	Do Nothing	Computer Simulation	CD ROM	DVD	Web Page	Video Game
Fidelity of Images						
Feedback Time						
Product Production Cost						
Shipping Cost						
Updatability						

The alternatives are in columns,
with the Do Nothing alternative first.
The criteria are in the rows.

Scoring Function Mistakes

- Mixing gains and losses
- Not using scoring functions

Equating gains and losses

- Team Excerpt
- 2.2 Number of Complaints
- 2.3 Number of Problems with the System
- 3.1 Number of Accidents per visit.
- 2.5.3. Number of Curses per day
- 5.2.6. Injury -- Is it possible for the design to inflict bodily injury on the batter? This is rated by the players on a scale of 1–10 (1 being no bodily harm, 10 being serious injury requiring hospitalization).

- These criteria are phrased negatively.

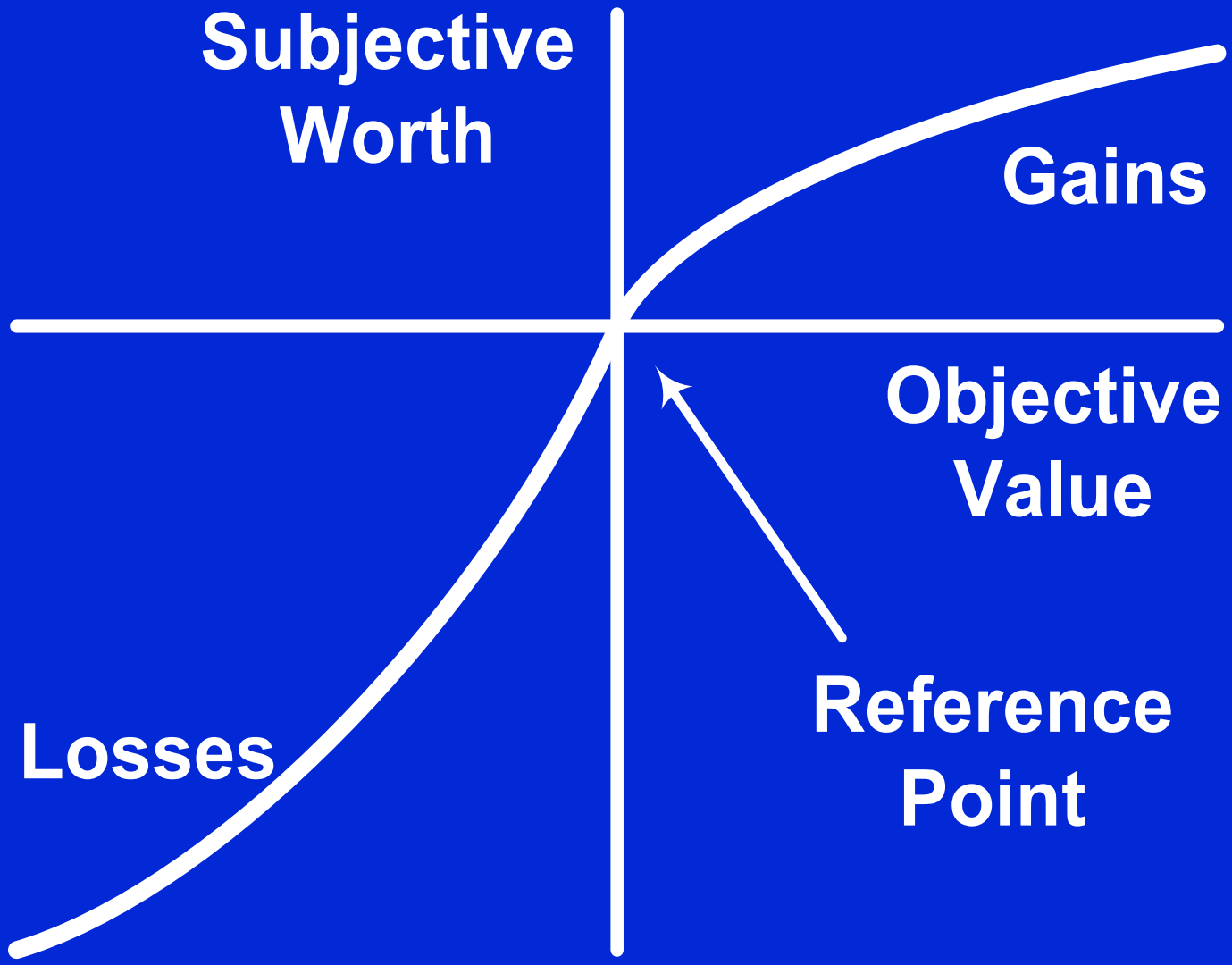
Equating gains and losses

- Suggested rewrite
- 2.2 Stakeholder Approval Rating (%)
- 2.3 Mean Time to Failure (MTTF)
- 3.1 Number of accident-free visits
- 2.5.3 Time without cursing
- 5.2.6. Safety – Mean time between injuries.

Explanation of mistake

- People do not treat gains and losses equally.
- Kahneman earned the Nobel Prize for explaining that people prefer to avoid losses rather than to acquire gains.
- Psychologically, losses are twice as powerful as gains.
- In a tradeoff study, you will get a different result if the scoring function expresses losses rather than gains.
- Scoring functions should only express gains.
- Linguistic comprehensibility principles state that criteria should be worded positively, so that more is better.
- You should use Uptime rather than Downtime, Mean Time Between Failures rather than Failure Rate, and Probability of Success rather than Probability of Failure.
- Finally, when using scoring functions, make sure that more output is better.

Gains and losses are not equal*

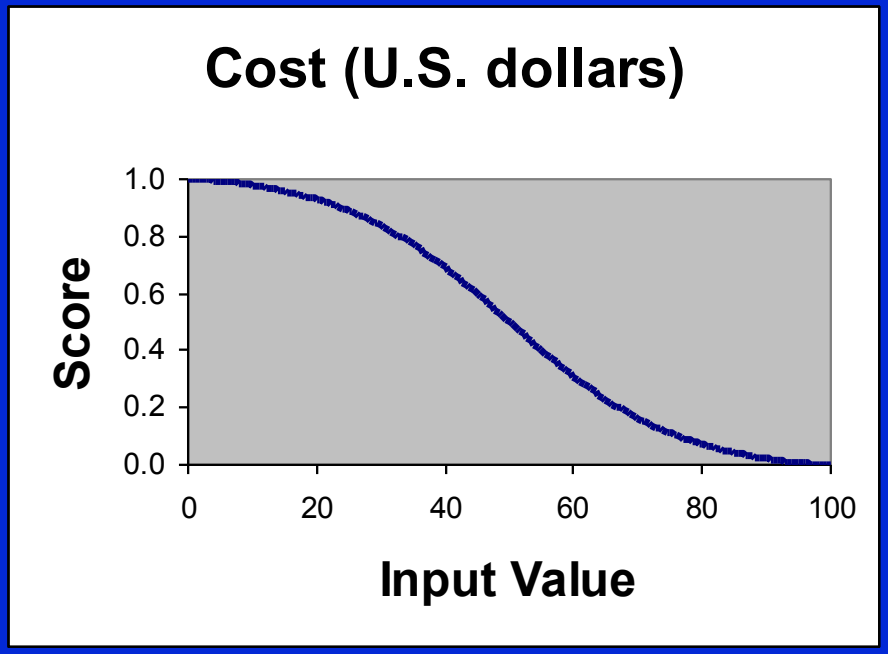


Not using scoring functions

- Team excerpt: Many teams did not use scoring functions.
- Evaluation data are transformed into normalized scores by scoring functions that should be created by a team of analysts, and be reevaluated with the stakeholders with each use. Scoring functions are also called utility functions, utility curves, value functions, normalization functions and mappings. Scoring functions prevent the preferred alternatives from depending on the units used. For example, add values for something that cost about one hundred dollars and lasted about a millisecond.
- Alt-1 cost $100 and lasts one millisecond, Sum = 100.001.
- Alt-2 cost $99 but it lasts two millisecond, Sum = 99.002.
- The duration does not have any effect on the decision.

Scoring functions

- Objective value is translated to subjective worth
- Input values become normalized output scores
- Scoring functions must be elicited from the stakeholder



Combining Function Mistakes

Summation is not always the best way to combine data*

Implying False Precision

Implying false precision

Team Excerpt for the SpinCoach		Normalized weights
Performance Requirements	Value	
1. Accuracy	8	0.235294
1.1 Spin Rate	10	0.384615
1.2 Launch Angle	8	0.307692
1.3 Launch Speed	8	0.307692
2. Consistency	7	0.205882
3. Ease of Use	6	0.176471
3.1 Portability	6	0.260870
3.2 Location	7	0.304348
3.3 # of Operators	10	0.434783
4. Opportunity	8	0.235294
5. Feedback	5	0.147059

Implying false precision

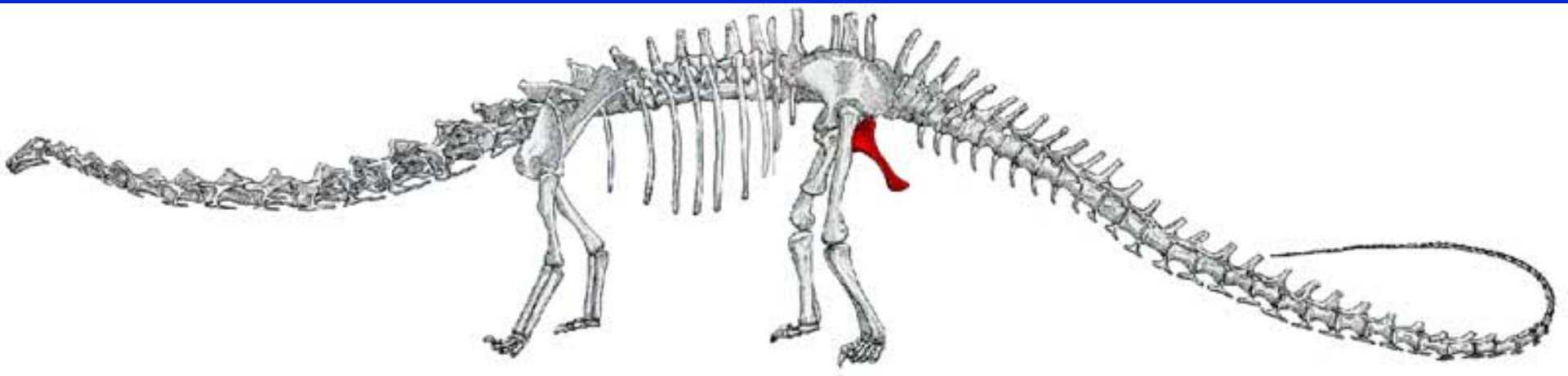
- The most common mistake in tradeoff studies is implying false precision.
- A SE might ask an expert to estimate values for two criteria.
- The expert might say, "The first criterion is about 2 and the second is around 3."
- The SE puts these numbers into a calculator and computes the ratio as 0.666666667.
- This is nonsense, but these nine digits might be dragged throughout the whole tradeoff study.
- Presenting nine digits after the decimal point obfuscates the equations and does not help to differentiate between alternatives.
- The Forer effect might explain why the SE does this: the SE believes that the calculator is an impeccable authority in calculating numbers. Therefore, what the calculator says must be true.
- Recommendation: In numerical tables, print only the number of digits after the decimal point that are necessary to show a difference between the preferred alternatives.

Implying false precision

Suggested rewrite for the SpinCoach			
Evaluation Criteria	Weight of Importance	Criteria Norm. Weight*	Subcriteria Norm. Weight*
1. Accuracy	8	0.24	
1.1 Spin Rate	10		0.38
1.2 Launch Angle	8		0.31
1.3 Launch Speed	8		0.31
2. Consistency	7	0.21	
3. Ease of Use	6	0.18	
3.1 Portability	6		0.26
3.2 Location	7		0.30
3.3 Number of Operators	10		0.43
4. Opportunities per Hour	8	0.24	
5. Feedback Response Time	5	0.15	

*Significant figures methodology suggests that the normalized weights have one significant digit. We have used two to make the calculations obvious.

Numerical precision*



Obviating Expert Opinion

Obviating expert opinion

- The most common mistake that we have found in design projects over the last 25 years is failing to talk with stakeholders and failing to consult experts and experienced advisors.
- The university and local industry is full of experts in the fields of every project that we have done over the last 25 years. In this time, very few teams have sought advice from domain experts.
- Why do people fail to seek the advice of experts and experienced advisors?
- The students rated the following possible reasons.
- In each category the reasons are arranged from the most frequent to the least.

Possible reasons for failing to talk with stakeholders, experts and advisors$_1$

- Timidity
- Perhaps they do not want to inconvenience the authorities or waste their time
- however people are not reluctant to seek the advice of physicians, tax accountants and lawyers
- To help overcome timidity
  - formulate your questions in advance
  - explain your problem so that the expert can quickly understand
  - state what you think the expert said before you leave

Reasons for not talking with experts$_2$

- Perhaps they fear that the incompleteness of their project will be interpreted as incompetence.
- Perhaps they think that a face-to-face meeting would display their naïveté. This is not a problem with e-mails, because most people do not expect e-mails to be thoughtful, coherent and grammatically correct: most students do not edit their e-mails or use a spelling and grammar checker on them.
- Perhaps they think that seeking advice reveals their ignorance, and that ignorance is shameful.
- Perhaps they think that consulting experts shows weakness, whereas going it alone shows strength.
- Perhaps they feel that, because they do not have a charge number, they cannot ask experts for advice.

Reasons for not talking with experts$_3$

- Importance
- Perhaps they do not realize the usefulness of face-to-face meetings with experts.
- Perhaps it is a matter of return on investment. Consulting experts takes time and effort. Perhaps these teams thought the improvement in their tradeoff studies would not be worth the effort of consulting experts.
- Perhaps the smart people think, "We can get an A without wasting our time talking to our advisor."
- Perhaps the new technology generation thinks that they can just Google the web for all the information that experts might provide.

Reasons for not talking with experts$_4$

- Importance
- Perhaps they noticed that other courses at the university do not provide world class experts to meet with them, so it must not be important.
- Perhaps they do not see a direct correlation between their grade and meetings with their advisor.
- Perhaps they perceive no added value.

Reasons for not talking with experts$_5$

- Time

  (obviously time and importance will be traded off)
- Perhaps they thought that they were too busy; meeting with their advisor would take time and effort; it would be hard to schedule meetings with their advisor. Maybe they were just lazy.

Reasons for not talking with experts$_6$

- Communication
- Perhaps they have had no experience initiating a meaningful conversation with a stranger and are therefore reluctant to do so.
- Perhaps they do not know how to talk face-to-face with an expert. After all, for most of our young people, communication is done by cell phones, twitter, the internet or e-mail. So they are deficient in face-to-face communication skills.

Reasons for not talking with experts$_7$

- Perhaps they have been taught that engineers work alone: after all, cooperating on exams is frowned upon. However, in the modern industrial environment, engineering is done by teams and when success is important consultants are hired.
- Perhaps they are reluctant to change or they don't want to do it someone else's way. If you ask for advice, then you should follow the advice you are given.
- Foreign students said, "It's embarrassing to show weakness in the English language" and "Our culture teaches do not approach an advisor or mentor."

"He who trusts in himself is a fool, but he who walks in wisdom is kept safe" (Proverbs 28; 26).

Summary of mental mistakes

- We examined 110 project reports composed of over 8000 pages of text that had been submitted over the last two decades .
- We found 808 mental mistakes.
- We selected the two dozen development cases (team excerpts) that are in this paper, and another 50 cases that were used for testing.
- Then 20 Raytheon engineers and 50 University of Arizona students tried to identify the mental mistakes in the 50 excerpts of the test set. The average agreement was about 80%.

Mental mistakes detected

Mental Mistake	Number of mistakes detected
Not Stating the Problem in Terms of Stakeholder Needs	62
Vague Problem Statement	65
Substituting a Related Attribute	24
Dependent Criteria	75
Forer Effect	61
Weight of Importance Mistakes	11
Anchoring and the Status Quo	69
Equating Gains and Losses	46
Not Using Scoring Functions	32
Implying False Precision	59
Obviating Expert Opinion	85
Sensitivity Analysis Mistakes	91
Other Mental Mistakes	128

Who cares?$_1$

- Who cares about mistakes in doing tradeoff studies?
- Consider the San Diego Airport Site Selection Tradeoff Study.
- This was a large, expensive, publicly accessible tradeoff study that contained mental mistakes
- It took six years and cost 17 million dollars.
- When its results were presented to the voters in November of 2006, the voters turned the proposal down and the $17M was wasted.
- They did a tradeoff study, but only four of the ten tradeoff study components were utilized: Problem Statement, Alternate Solutions, Evaluation Criteria and Preferred Alternatives.

Who cares?$_2$

- They used five evaluation criteria: Aeronautical, Environmental, Market, Military and Financial. The criteria were arranged hierarchally with subcriteria and subsubcriteria. However, the criteria did not have weights of importance or scoring functions.
- They had a dozen alternative sites, including the Do Nothing alternative. They often added and deleted alternatives. For example, the floating platform in the Pacific Ocean was dismissed early. The Campo and Borrego Springs sites were added late, so these sites had greater visibility in the public mind. However, the Campo and Borrego Springs sites were similar so, because of distinctiveness by addition of alternatives, they faded away.

Who cares?$_3$

- They did a rudimentary sensitivity analysis looking at changes in their planning parameters at two different demand levels. They also did a small sensitivity analysis showing changes in total cost as a function of available funding (without issuing bonds or increasing taxes).
- The interim results of the study were continually being reported in the press. So they certainly received a lot of expert opinions.
- However, in the end, the voters did not trust the study. The Authority did not show a burning platform or a compelling reason for change. It seemed that they only considered future business growth.

Who cares?$_4$

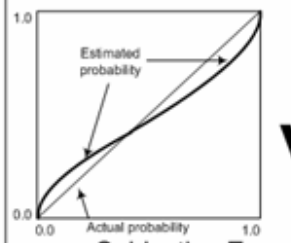
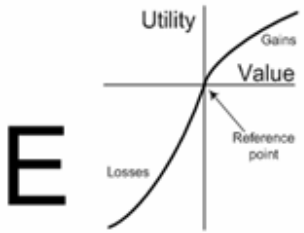
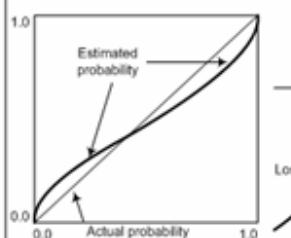
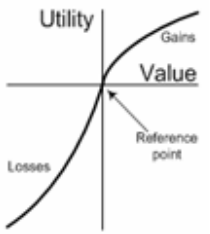
The ballot proposal asked, "Should Airport Authority and government officials work toward obtaining 3,000 acres at MCAS Miramar by 2020 for a commercial airport, providing certain conditions are met?" It was turned down 38% to 62%.

Good industry practices

- for improving the probability of success of tradeoff studies include
  - having teams evaluate the data
  - evaluating the data in many iterations
  - expert review of the results and recommendations*

Purpose of teaching tradeoff studies

- Emotions, illusions, biases and use of heuristics make humans far from ideal decision makers.
- Using tradeoff studies thoughtfully can help move your decisions from the normal human decision-making lower-right quadrant to the ideal decision-making upper-left quadrant.

	Objective Probability	Subjective Probability
Value	EV Rational Behavior	 V Subjective Expected Value
Utility	 E Expected Utility	  Human Behavior

Improving the tradeoff study process

- Inform your decision makers about how mental mistakes affect tradeoff studies, (forewarned is forearmed)
- Encourage a long-term institutional decision horizon
- Use a team approach
- Create frequent iterations
- Institute both expert and public reviews
- Finally try to reduce mental errors by using the recommendations of this presentation

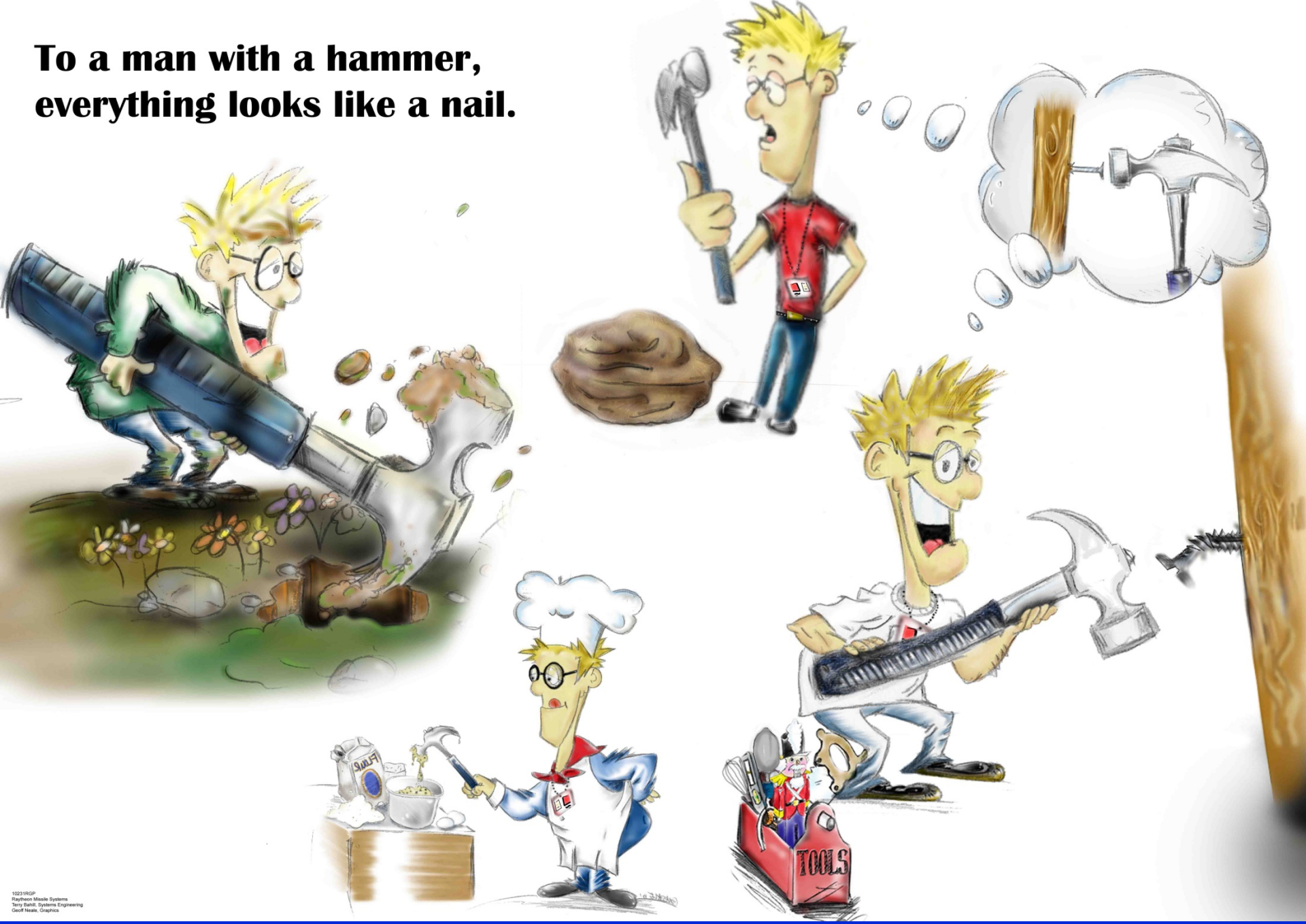
Proper Wine Tasting Technique

See

Smell

Slurp

To a man with a hammer, everything looks like a nail.

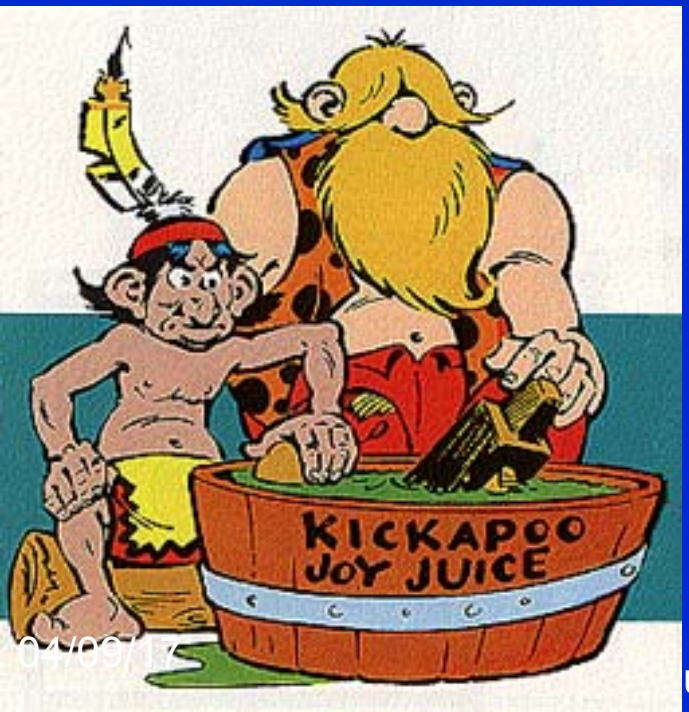


10231RGP
Raytheon Missile Systems
Terry Bahill, Systems Engineering
Geoff Neale, Graphics

Problem solving methods*

Backward chaining

- The medicine man has a 4-ounce bottle and a 9-ounce bottle, but I want exactly six-ounces of Kickapoo Joy Juice.
- How does the medicine man meet my needs?



4 ounces

9 ounces


Research
to Recycle
INCOSE