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Psychology of Cost Estimating

If you've been a cost estimator for even a month, you've already started to learn about the dark side of cost estimating. It can manifest itself with a simple sideways glance from an engineer, or a torrent of angry questions from a program manager. But we all know the warning signs as we humbly attempt to brief a stakeholder on the latest iteration of our cost estimate. It can typically be boiled down to two types of reactions: 1) this is NOT what I was expecting to see after I did my own back-of-the-napkin estimate, or 2) this number is OVER our approved budget and inconvenient to me, so it must be wrong.

When the directorate I was working in began a "Learn Everything" initiative, geared towards giving employees dedicated independent study time each week, I jumped at the opportunity to see what answers psychology might have for the baffling but consistent reactions and situations I'd encountered during my 20+ years as a cost estimator for the Air Force. After pouring through a stack of books over the next year, it turned out psychologists had been looking at this peculiar human behavior for a long time and had a plethora of explanations. As the late, great comedian and social commenter George Carlin once said, "think of how stupid the average person is, and realize half of them are stupider than that."

The focus of this paper will be examining a few of the more prevalent psychology concepts that impact the cost estimating process, providing real-world examples from my research that touched on these concepts, and diving into examples from large ACAT I programs that I've supported during my time with the Air Force. The concepts and examples provided are the tip of the iceberg in terms of the sheer impact of psychology on the cost estimating process. The intention is to narrow the aperture to situations that arise most frequently, and hopefully, continue to examine more psychology concepts in the future.

Perhaps the biggest challenge we all face as cost estimators is getting access to data, or even finding the most applicable data required to complete a cost estimate. When those situations occur, we're forced to rely on engineering assessments, or what I'll refer to as human judgement, when we simply can't find or access the data. It turns out that the field of psychology has been studying the concept of using data versus human judgement to predict future events for the last fifty years. Not only psychology, but tangential fields of study like sociology, anthropology and economics have all been studying the fidelity of subjective predictions against statistical predictions. In over 200 studies conducted during this time, the results have fallen consistently in favor of statistical, data-driven predictions. Sixty percent of the studies proved that data was greater than subjective predictions, and the other forty percent proved they were equal. In other words, precisely zero of the studies proved that subjective, human judgement predictions were

better than statistical predictions. When you factor in what it costs per hour to pay a subject matter expert for their time versus the readily available and free data we have access to within the DoD cost estimating community, it's not much of a debate.

It turns out that human beings are inconsistent in making summary judgements of complex information, and there's little in this world more complex than the DoD acquisition process. If you've ever seen the Defense Acquisition University (DAU) chart that lays out the Joint Capabilities Integration & Development System (JCIDS), Defense Acquisition System (DAS) and Planning, Programming, Budgeting and Execution (PPBE) system, affectionately known as the "horse blanket chart", you know this to be true. One of the studies conducted showed that experienced radiologists contradict themselves 20% of the time when reviewing the exact same x-ray, so it's not just cost estimators or acquisition professionals who fall prey to this trap. The key takeaway for cost estimators is that regardless of data availability, we still need to rely on human judgement in the cost estimating process so it's important to understand that human brains have limitations that can impact judgement.

Now that we've established that our human brains have limitations, let's exam how our brains actually function. Nearly all of the psychology material I reviewed built off the basic concept established by Daniel Kahneman, that the human brain has two separate systems of thought. Kahneman, who just passed away last year, had been a leading voice in psychology for the last 60 years. He was a Nobel Prize winner in Economics for his research with partner Amos Tversky on human judgement and decision making with uncertainty, and how that applies to economic decision making. His research concludes that the human brain has a System 1, and a System 2, which can both be utilized to make decisions. System 1 "operates automatically and quickly, with little or no effort and sense of voluntary control." System 2 "allocates attention to the effortful mental activities that demand it, including complex computations. The operations of System 2 are often associated with the subjective experience of agency, choice, and concentration."

In terms of application to the cost estimating process, this concept is interesting when it comes to the environment in which we conduct interviews with subject matter experts (SME). If you're sitting in a meeting with ten people around a conference room table and put someone on the spot to provide a best case, worst case, and most likely input for your cost estimate, the engineer is more likely to utilize System 1 to provide the quickest answer that comes to mind. Alternatively, if you send them a list of questions days in advance of the meeting and provide time for System 2 utilization, you'll get inputs that are well thought out with more uncertainties considered. In military environments and program offices with a quick pace, it behooves us as cost estimators to slow the acquisition train down when needed to ensure we're getting the best answers possible, not the most readily available answers. This also impacts how to determine risk assessments in your cost model. It's easy to give certain inputs a cursory look and provide a standard risk assessment that we're familiar with for that type of input variable, but taking the time to truly discuss each risk individually and give the experts time to think through the uncertainty will result in a better cost estimate.

Another psychology concept that appeared to impact the cost estimating process is a cognitive bias which occurs when humans overestimate their understanding of a specific topic or situation, otherwise known as the illusion of understanding. Two of the common biases that

Kahneman highlights in his research are the narrative fallacy and the halo effect. Narrative fallacy refers to flawed stories of the past that shape our expectations for the future. As an ardent New England Patriots fan, I immediately thought of the severing of the Bill Belichick and Tom Brady partnership at the end of their final Super Bowl run. The majority of fans assumed that Coach Belichick was the primary reason for all the success, so losing Tom Brady would not impact the winning machine of the previous two decades. Instead, the Patriots slid to the bottom of the league and watched Tom Brady move to Tampa and win yet another Super Bowl with an entirely different coach and team. Oh boy, were we wrong!

The halo effect refers to the tendency to like or dislike everything about a person (or in our case a program). A good example of this comes from the public debates over the last few years about judging the art versus the artist. I had a friend in college who was a massive Michael Jackson fan, and when allegations of inappropriate behavior began piling up, she simply refused to believe them and it had no impact on her fandom or view of his art. The same can be said of numerous Penn State football fans and their continued lionization of Joe Paterno. The flip side of the coin is the public reaction to Woody Allen's allegations of inappropriate behavior when fans immediately boycotted watching his movies and actors declared him persona non grata and refused to work with him. He may be a bad guy, but it can still be true that the opening scene of the movie *Manhattan* is as brilliant and beautiful as it was before we knew about his personal life.

When it comes to data collection, cost estimators can easily fall into these traps when considering what program data to use, or what SME to interview. One narrative fallacy situation I've encountered personally involved other Air Force programs reaching out to ask for CSDR data on a program in the division I supported as the cost chief. The program had been cancelled and was an epic failure by all accounts (more to come on this fateful program later), but fellow cost estimators continued to ask for the CSDR's. I considered responding with a negative and a quick note saying the data isn't relevant because the program was cancelled two years into a five-year program, so why bother with incomplete data? After a group discussion with all the functionals, we decided to send the data with the caveat that the cost data is not in and of itself useful, but it's definitely worth looking into WHY the program failed if you're working on an analogous effort. We offered to have the cost team and the program manager meet to discuss the CSDR's along with the program history and lessons learned. The program was a failure, but it didn't mean that all data from the program was useless.

I also encountered the halo effect up close and personal as a young cost estimator when working on a program with two engineers, either of whom I could utilize to gather technical inputs for my cost estimates. One was an extremely large, physically intimidating man with a beard down to his waist and the emotional demeanor of a junkyard dog. The other was an average sized man with an easy smile, and a gregarious and engaging personality. Naturally I chose the latter when I had to ask for technical inputs for the cost estimate. Over time it became clear that the technical inputs were not high quality, and contractor proposals consistently came in much higher than my estimates. The next time I finally put aside my fear and asked the other engineer for his help with the estimate, and besides not biting my head off, it became clear that he was far more knowledgeable and my estimates were finally in line with the contractor proposals. Sometimes we need to take a step back and ask ourselves "why this program?" or "why this person?" and make a conscience effort (using System 2!) to avoid these pratfalls based on cognitive bias.

Let's return to the example referenced at the very beginning of the paper for the next psychology concept, which mentioned common reactions from stakeholders when briefing an updated cost estimate. What is it about cost estimators and cost estimates that evoke such dramatic reactions from people? After a few years on the job you start to realize these incredulous reactions are standard fare and have nothing to do with trust in your personal abilities. This is just another wonderful part of our human psychology and is explained by the concept of anchoring. Anchoring occurs when people consider a particular value for an unknown quantity before estimating that quantity. It's almost like they studied this specifically for cost estimators! Anchoring can be used as a negotiation tactic like on the show Shark Tank, where the entrepreneur will anchor negotiations with the sharks by asking for \$200,000 for 5% of the company. It can also be used as a priming effect where a stakeholder demands a radar is fielded within 5 years, and magically, coincidentally, the program manager's schedule reflects a 5-year effort, all data to the contrary be damned.

There are many times when the acquisition or PPBE process dictates that we need a cost estimate done by a certain date, even if we don't have all the relevant data that we need. The estimate gets reluctantly completed, the total cost gets publicized to certain stakeholders, and once everyone has seen this number, we finally receive the data that drives a reasonable update to the baseline estimate. The explanation for the update may be reasonable, but the stakeholders may not have a reasonable reaction if the new estimate is higher (and frankly, when is it ever NOT higher). Their brain was already anchored on say, \$150M, but now it's actually \$175M? If the program is already funded for \$120M, just imagine the amount of anchoring effect occurring as the delta continues to increase over time. I've been involved in other situations where there's no instigating factor driving a need to release a cost estimate outside the program office, other than someone asked for it or wanted it. In these instances, you really have to consider whether you want to publicize a low fidelity estimate immediately, especially if you suspect the number will go higher over time. Why start anchoring now? Managing expectations and having difficult conversations with program managers can reduce, minimize, or eliminate these situations (especially when a budget hasn't been allocated yet).

The concept of compounding is familiar to most of us from our finance classes in college, but even for savvy cost estimators the impacts of compounding can be challenging. The concept is simple, that small increases over time serve as the fuel for continued growth, and is typically associated with investing or portfolio growth. Speaking of portfolio growth, let's use Warren Buffett as an example of how our brains struggle to grasp the impacts of compounding. As of 2020, Warren Buffett's net worth was calculated at \$84.5B, which isn't shocking if you follow the stock market. What is shocking is that \$84.2B was accumulated AFTER his 50th birthday, and \$81.5B was accumulated AFTER his 65th birthday! In order to truly understand that accumulation you can certainly factor in his acumen as an investor, but the most important variable is time. There are plenty of other investors with similar track records of annual % gains, but what sets Buffett apart is that he started investing in the stock market at age 10. By the time he was 30 years old he had already accumulated the equivalent of \$9.3M in FY20 \$. How many of us started investing at age 10 and had \$9M in the bank by age 30? Exactly, otherwise you wouldn't be sitting here trudging through this paper!

Many weapon systems that we complete life cycle cost estimates for can take years to develop, years to procure and field, then a decade or two in the field to operate and sustain. When considering a life cycle cost estimate that displays information running through FY50, compounding plays a large role in the total numbers. Operational costs for old, heavy aircraft like the E-3 AWACS include expensive fuel costs, replacing DMS equipment every few years, and large fluctuations in commodity pricing which are all driving significant out year costs. Tack on the impacts of normal inflation and commodity specific escalation and costs become astronomical and hard to conceptualize. On a Spruill chart, you may have twenty years of Operations and Sustainment costs lumped into a single column labeled "To Complete." If cost estimators struggle to articulate this, imagine other stakeholders without a quantitative math background trying to understand it. This isn't a concept we can avoid, like anchoring, but we can take extra time with stakeholders and walk the dog with them when briefing life cycle cost estimates.

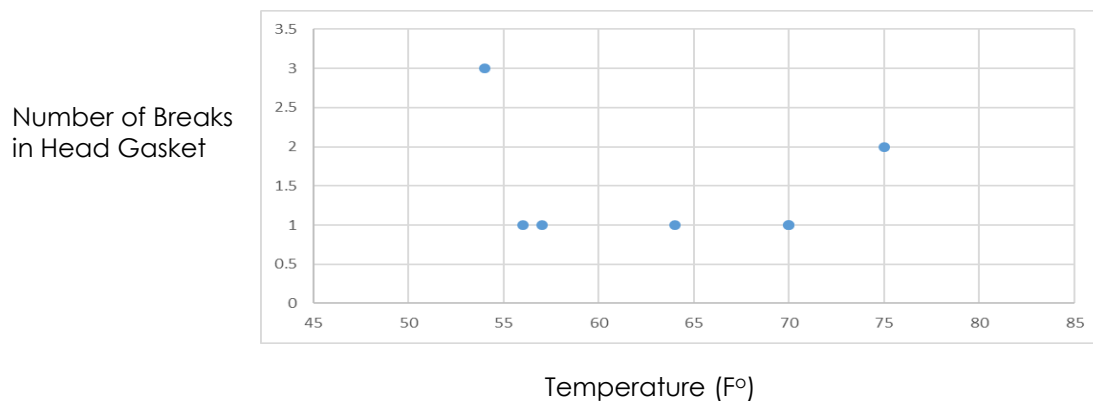
The final psychology concept I'll cover before diving into real-world examples is simple to understand but inevitably taken for granted, which is interpersonal communication. Dale Carnegie wrote the infamous tome *How To Win Friends And Influence People* in 1936 and it continues to be as relevant and eye opening today, especially in an era of internet trolling and keyboard warriors. The book covers nine principles for influencing people, all of which are relevant, but I chose five that most pertain to the cost estimating field to highlight: 1) begin with praise and honest appreciation, 2) talk about your own mistakes before criticizing the other person, 3) ask questions instead of giving direct orders, 4) give the other person a fine reputation to live up to, and 5) make the other person happy about doing the thing you suggest. It's pretty simple: you catch more flies with honey than vinegar. That's it.

Begin every interaction with the people involved in the cost estimating process with a heaping dose of empathy. Consider how you react when someone demands something from you, rather than asking you politely. Consider how you felt when asking your parents to stay out later on Friday night and they answered, "because I said so" instead of providing an actual explanation about the dangers of drunk driving and nothing good happens after midnight or some other words of parental wisdom. How you talk to people matters, especially when you need something from them. And we sure as hell need help from other functionals when we're trying to complete a cost estimate. Be complimentary but sincere. Be polite but explain why a certain deadline is looming. My favorite tactic with an unhelpful program manager is to deploy the ol' "if I don't get any help from the team, the estimate will be too low, and you won't be able to maintain schedule and stay within budget." That's usually a last resort reserved for those extra special program managers who prefer the cost estimators didn't exist, but explaining how this can impact them individually is better than throwing up your hands in frustration.

Now that we've reviewed a few germane psychology concepts that impact cost estimating, let's look at real-world examples that highlight this human behavior. I'll start with an example from Daniel Kahneman himself because even experts who study the human brain and its limitations are not exempt from these situations. Later in his career he led a team of fellow psychologists that were tasked with developing a high school curriculum for a class on the science of decision making. He queried the team of experts on how long they expected to take to develop the curriculum, and responses ranged from 1.5 to 2.5 years. During follow-up questions with one team member, he casually asked why they predicted 2 years, and they just shrugged and said that was their best

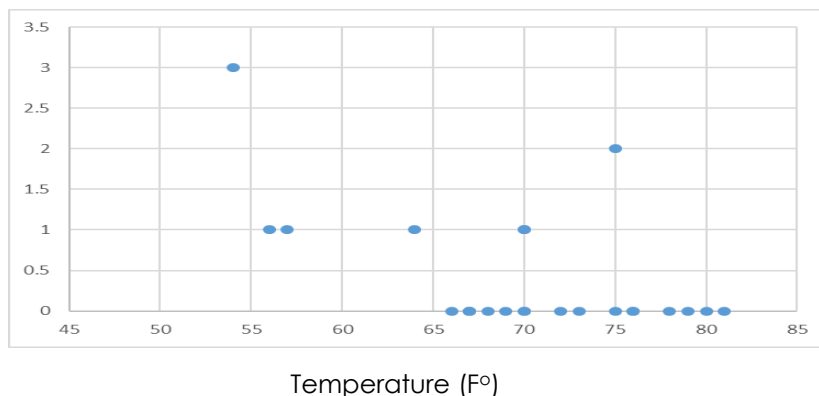
guess. Probing some more, Kahneman found out that this person had actually been on similar teams to this one, and 40% of the time the project never finished, and recalled one instance taking 7 years! All this data was available when Kahneman asked the first time, but they chose to ignore the data entirely. Just to tie a bow on this anecdote, his team did tackle the project; it took 8 years to complete, Kahneman was no longer on the team by the end, and the customer didn't want the final product because it was already obsolete. Sound familiar to any acquisition programs you've ever worked on?

The next example comes from the book *Range* and features a story from Harvard Business School. The professor presents the class with a case study asking each of the students to resolve this simple premise: decide whether the Carter Racing Team should race or not given the following criteria. The CRT has a race in one hour, it's expected to be 40 degrees outside at race time, and they'll be given some data on engine failures but can try asking for more data before they make their decision. The argument for racing is: 1) they've been successful and finished top five in 12 of the 24 races, 2) with a win they'll gain additional and/or better sponsorships, 3) they'll get great exposure with the race being on national tv, and 4) if they don't race, they end the season with an \$80K loss but a good finish makes them profitable. The argument against racing is: 1) they've had engine failure in 7 of 24 races due to breaks in the head gasket, 2) the pit crew has made adjustments but haven't identified the root cause, and 3) if engine failure occurs on national tv they'll lose all sponsorships. The following graph represents the data provided by the pit crew, led by a high school dropout with no engineering experience but decades of racing experience. He suspects it's temperature related but hasn't had enough time to determine the root cause.



At this point the professor asks the students whether they would race or not given the facts above. Based on the lack of clarity in the failure data, including two failures that happened at 75 degrees, and the positives to be gained from a good finish in the race, all but one student raise their hand to say they would race. The one student that didn't want to race then asked the professor if she could see the data for all the races, not just the ones with engine failures. The professor says that data is available:

Number of Breaks
in Head Gasket



With the additional data provided it becomes clear that every race with temperatures below 65 degrees resulted in engine failure, and it will be 40 degrees at race time. Once again the professor asks the class to raise their hand if they want to race; this time no one raised their hand. Now for the even bigger twist. This is the actual data for the O-ring failures on the Space Shuttle Challenger leading up to its explosion soon after takeoff in 1986. NASA never asked for the complete set of O-Ring data from the contractor, only the failures. The contractor offered non-quantitative reasons for wanting to postpone launch, but this subjective data was ignored because it couldn't be quantified (or so they thought). All in all, it was unfortunately a massive error in human judgement with dire consequences that led to a loss of human lives. Human judgement limitations led many brilliant people to ask for the wrong data, the halo effect impacted decision-making based on NASA's sterling reputation, plus data was ignored that wasn't convenient like we saw in the Kahneman example above. It's a sad story but certainly one ripe with lessons learned on the frailty of human judgement.

Moving on, this is an example of anchoring on an Air Force special interest ACAT I program that defies all boundaries of human logic. During my time as cost chief for the Theater Battle Control Division our cost team were tasked with completing a quick-turn, one-day POE to support an unfunded requirements tasker. The Wide Area Surveillance program fielded a Block I analog configuration of a sensor at a few sites but intrigued by pursuing a Block II effort in a digital configuration for future sites. Given one day to complete the POE, the program office team provided access to precisely one engineer for a half hour, and we utilized a combination of Block I cost data, SME inputs, and what I'll charitably call "marketing material" from the contractor to complete the estimate. Despite the high cost of roughly \$25M, miraculously the funding got approved and we received RDTE funding for that fiscal year.

Fast forward a few months and as we engage with the contractor and learn more about the technical solution and start to receive proposals, the \$25M estimate appears to be low. Based on ground rules and assumptions provided by our program office team, the eventual scope of the effort that went on contract was less than initially estimated in the first place. Consider it a minimum viable product situation, so the cost had already increased while the scope had already decreased, not exactly an encouraging trend. Over the course of the next FOUR years, the contractor mismanaged and bungled this effort to the point where the cost had risen to over \$50M and the scope decreased again. During the entirety of those four years, the only internal discussions within the program office team and the user community were focused on the cost

estimating team's poor initial cost estimate and our perpetual inability to predict the skyrocketing cost of the effort. Not until a new Division Chief and PM entered the picture did anyone start to ask, "are we properly managing the contractor?" or "why is the contractor performing so poorly, should we stop sending them funding?" The anchoring effect was so strong with all the initial stakeholders that even after explaining the ramifications of completing a one-day POE with a half hour of support from an engineer for a complex digital sensor, it took four years and a new leadership regime to move past that.

For the final example I'll detail how the narrative fallacy about the origin of the ACAT I Three-Dimensional Expeditionary Long-Range Radar (3DELRR) program led to a disastrous situation which resulted in program cancellation only two years into the five-year effort. The program was initiated due to the legacy TPS-75 radars (fielded initially in the 1960's) failing, the system A₀ falling substantially, spares being depleted, and failing units being cannibalized to support remaining operational units. The 3DELRR acquisition strategy was guided by a significant Foreign Military Sales (FMS) market that began lining up to purchase this long-range mobile radar solution after the initial US RDTE investment. The industry winner of the RDTE contract would be setup for years of long-term FMS profits and any follow-on Contractor Logistics Support (CLS) contracts, so the competition to win this contract was intense. This cutthroat competition led to the AF getting a great business deal on the RDTE contract, with a bargain basement price of \$50M for two radars, based on significant Internal Research and Development (IRAD) money being invested by the major prime contractors. So, what happened to make this a cautionary tale instead of a roaring success?

Price overtook technical and schedule concerns and informed the strategy to the maximum extent possible very early on in the program. The intense competition led to a protest after initial contract award, a lawsuit was filed against the AF by the winning bidder due to the resulting decision from the protest, the source selection process was restarted, multiple bids were received for \$0, source selection was restarted a third time to add LRIP and FRP options to the scope as tiebreaker criteria, and finally a contract was awarded to the same initial winner from two years prior. During those whirlwind two years the technical requirements started to shift, world events led to changing operational threats and missions, and cyber requirements for US and FMS customers started to deviate from what used to be a common baseline. All of this led to a contractor that was nowhere near as motivated as they had been when the competition kicked off, since the FMS profit stream looked less and less likely. Two years into the RDTE contract the program was already three years behind its schedule, and the program office cancelled the contract and pivoted their acquisition strategy. The focus of the program became the incredible price tag while the reality of the incredibly old technology failing in the field drifted into the background. This should have been a program focused on technical and schedule requirements, but the narrative fallacy about the great business deal emerged based on that initial market research. Once again, lots of incredibly smart people missed the forest for the trees.

As cost estimators we rely on human judgement and interactions for a significant part of our job, no matter how much quantitative analysis is done. Understanding some of the basic elements of psychology, human behavior, and decision making can enhance our job performance and prevent us from being stuck in unnecessary situations on our programs. As a final word of caution, an understanding of psychology is not going to eliminate these issues, but it can help guide the way we interact on a daily basis both professionally and personally. These psychology concepts

discussed here are a small representative of the myriad ways that cost estimators can benefit from this field, so I highly encourage everyone to continue researching and consider how psychology concepts affect your current estimates and programs. Ultimately, we need other people to help us do our job, so we can't forget that psychology can be a critical tool for our tool belt. At least until AI takes over our job.

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