AGAINST ALL ODDS
EPISODE 20 – "RANDOM VARIABLES"
TRANSCRIPT

FUNDER CREDITS

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INTRO

Pardis Sabeti
Hello, I'm Pardis Sabeti and this is *Against All Odds*, where we make statistics count.

Let's spend some time with everyone's favorite random phenomenon – the coin flip! I have an evenly weighted coin, just as likely to come up heads as tails on each flip. What if I toss it four times in a row?

Here's the sample space for our little experiment – remember that's every possible outcome from the four consecutive flips. Each of these outcomes is equally likely. But say we're only interested in the number of heads that come up – we'll let x equal the number of heads we toss. We're now focusing on what statisticians call a random variable: the numerical outcome of a random phenomenon. We don't care anymore when in the sequence of tosses we get heads or tails, just the overall number of heads that come up. The probability distribution of a random variable x tells us the values that the random variable can take on and the probabilities of each value.

In our four coin tosses, the random variable x could equal 0, 1, 2, 3, or 4. It's a discrete variable since it has a finite number of possible values. Each of these outcomes is possible but not equally likely as you can see in the chart. The sum of all the probabilities is 1. $p(x)$ is how statisticians denote the probability associated with a particular value x. So for instance, $p(0)$ is the probability that the value of the random variable is 0.

We can turn the model into a probability histogram. The horizontal axis shows us the possible values of x and the height of each bar represents the probability for that value. Here you can see that 2 is the most likely number of heads to come up in a string of 4 coin tosses. The histogram tells us what we can expect from the data, if we were really to run the experiment over and over again many times. Instead of working with data, we can use the probability distribution.

The stakes aren't very high when I'm just flipping my half dollar and idly thinking about coin toss probabilities. But such calculations can be a matter of life and death when the events are critical equipment failures.

January 28, 1986. The space shuttle Challenger is ready for takeoff. The launch is monitored from Mission Control in Houston.

> **Mission Control**
> Roger roll, Challenger.
> Good roll, flight.
> Rog, good roll.

Challenger, go with throttle up.
Roger, go with throttle up.

All operators, contingency procedures in effect. Don't reconfigure your console. Take hard copies of all your displays. Make sure you protect any data source you have.

Ronald Reagan
The death of the astronauts and destruction of the space shuttle Challenger will forever be a reminder of the risks involved with space exploration, and we will always remember the Challenger seven.

Pardis Sabeti
Almost immediately after the accident, President Ronald Reagan appointed a commission of experts to investigate its cause. Their eventual conclusion: the accident was most likely caused by O-ring failure. O-rings sealed the field joints holding together the rocket boosters that would lift Challenger into orbit. The O-rings were supposed to contain hot, pressurized gases within the boosters. That morning, due to O-ring malfunction, one of the field joints failed.

A broader finding of the commission was that NASA hadn't adequately evaluated the risks of this failure or any other.

So could the disaster have been predicted? The first step in a probability analysis of the field joints is to calculate the probability of failure in one of them.

Bruce Codley
Under the Challenger flight conditions the probability of failure of a particular field joint was, we came out with, .023. That means the probability of success of an individual field joint would then be, what would that be, .977. Okay? Now, that's the probability of the success of one field joint. But there were six field joints. So for the whole system to succeed, all six had to succeed.

Pardis Sabeti
If even a single field joint out of the six failed, that would have caused a shuttle accident. So we are interested in the probability of a safe flight with none of the field joints failing. In our probability distribution table, we let our random variable x equal the number of failures. And we want to determine $p(0)$ – no failures. Like when we were calculating the number of heads from a series of coin tosses, we're interested in the overall number of failures, not the actual outcome for each individual field joint.

We can use the Multiplication Rule to calculate the overall reliability of the shuttle rockets. This rule is both simple and powerful. It says that if two events, A and B, are independent, then the probability that both events will occur is the product of their individual probabilities.

Remember the probability that each field joint would succeed was .977. That sounds pretty reliable. But there are six field joints. For the shuttle to succeed, all the joints must succeed. So we have to multiply .977 times itself 6 times, once for each of the field joints. Now the reliability or probability of success for the mission drops to about .869, or about 87% – very different from the original .977. It's possible to compute the other individual probabilities, but for now we will simply use the Complement Rule to calculate the likelihood of there being at least one field joint failure. Remember, all the possible outcomes together must have a probability of one. 1 minus .87 is .13.

> **Bruce Codley**
> You know, .977 sounds like a high probability. But in reliability rule it's not at all a high probability because that .977 now, when you multiply it by itself 6 times over the 6 field joints, reduces to .87 and now you're playing Russian roulette, because the probability of failure is .13. And that's sort of like playing Russian roulette with 8 bullets!

Pardis Sabeti
The probability of an individual field joint failing is pretty low, but the probability of at least one of the six failing is rather high, especially considering that astronauts' lives are at stake. Each field joint needed to have a probability much closer to 1 than .977 in order to ensure the shuttle mission's long-range success.

> **Bruce Codley**
> A typical trick that engineers use to get an individual part to have a very, very high success probability is to put redundancy in – that is a backup for that part. And in the shuttle, for the field joints, the original design was that they had two O-rings – the primary O-ring and the secondary O-ring. And the secondary O-ring was intended to back up the primary O-ring in case the primary O-ring would fail. So, and that's why they originally felt that they had a very, very safe joint because of the redundancy in the O-rings.

Pardis Sabeti
If the O-rings had really been independent, each with a small probability of failure, then by the multiplication rule, the probability of both failing would have been extremely small. But it turned out that the O-rings actually weren't independent: they shared a common failure mode called joint rotation.

When a joint rotated at takeoff, a large gap was created that affected both O-rings and allowed the dangerous hot gases to escape. So in reality the probability of failure was even higher than the .13 we calculated, since the O-ring failure events were not independent.

Bruce Codley
If you assume independence, you get very, very reliable things. But in the real world, things may not be independent. There may be common failure modes, common causes. And if there's common causes floating around, things are no longer independent. And therefore, they're not as reliable.

Pardis Sabeti
Over 200 improvements were made to the next space shuttle after the Challenger disaster, including the addition of a third O-ring, which was truly independent from the other two it was designed to backup.

Announcer
3, 2, 1, 0 and liftoff!
[Cheering]
Liftoff! Americans return to space as the Discovery clears the tower.

Pardis Sabeti
NASA successfully launched shuttles almost a hundred more times before retiring the space shuttle program in 2011. Of course a complex, state of the art technology like the shuttle system could never reduce the risk of failure to 0 – and in fact another disaster occurred in 2003 when the space shuttle Columbia disintegrated on re-entry to Earth's atmosphere. Though the O-rings weren't to blame this time, it was a tragic reminder of the risks of space exploration and the need for continued, rigorous analysis.

For *Against All Odds,* I'm Pardis Sabeti. See you next time.

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