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Playing the Killer Slot Machine

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Playing the Killer Slot Machine (a Tutorial on Risk)

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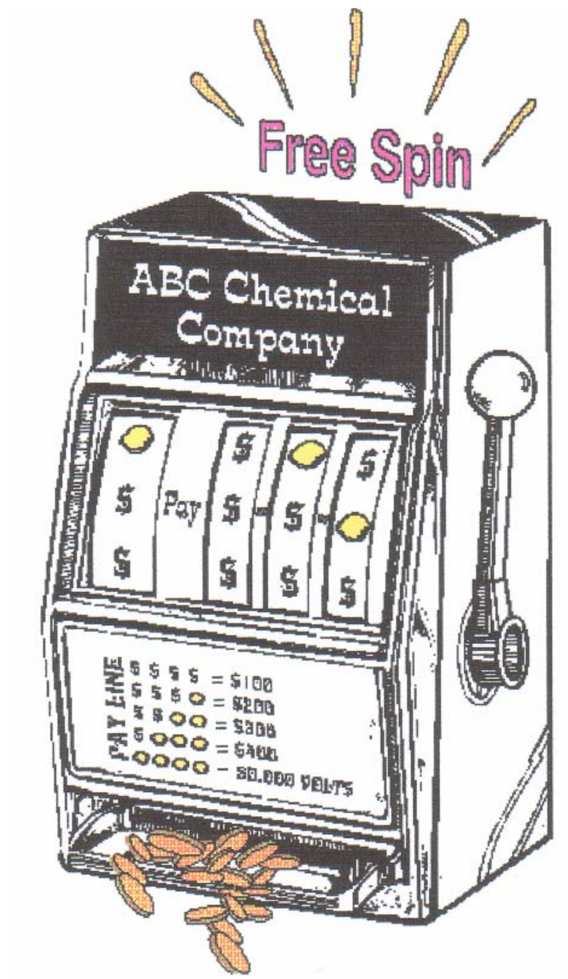
ABSTRACT

A new casino has opened in Las Vegas, and its slot machines pay well on every pull of the handle – except for a chance that on any pull of the handle, the machine may be charged with 50,000 volts and the player will be fried. Would you play the game? This paper explores how the acceptability of risk changes under a variety of circumstances. It also explores how these same principles apply to hazard analysis teams that are judging the acceptability of engineered and administrative controls, and whether or not to generate recommendations.



TUTORIAL

As you step into the casino lobby, your eye is immediately drawn to the mob of people milling around an enormous, gold-plated slot machine. Then, you notice a neon sign above the machine flashing “FREE SPIN” and television cameras filming the event. “Must be some new game show,” you think as you join the throng. You work your way closer to the stage, and you see why everyone is clamoring to pull the handle — this machine pays off with every spin. In the excitement, you start jumping up and down, hoping to be noticed and selected by the master of ceremonies. Finally, your effort is rewarded, and a liability waiver is thrust into your hand as you are being pulled toward the stage. Your signature is required, they say, before you can play the game. Reading hurriedly, your eyes focus on:

**“WARNING: ANY SPIN RESULTING IN ALL LEMONS
ON THE PAY LINE CAUSES DEATH”**

Will you sign the waiver?

This is a classic risk-based decision. There is no right or wrong answer, only a decision based on the individual's (or organization's) risk acceptance criterion. In this example, the negative consequences are severe. For some people, that fact alone is enough to dissuade them. But, most of us willingly engage in activities, such as driving or flying, with potentially fatal consequences. What other factors influence our willingness to play the slot machine?

- **How many wheels are on the machine?** Each wheel is essentially a layer of protection. More people would be willing to play a machine with ten wheels than a machine with only one wheel.

- **What percentage of each wheel's positions are lemons?** Each lemon represents a failure of that protective layer. The lower the percentage of lemons, the more dependable the protection, and the more people would be willing to play.

- **Are all the wheels spinning?** Periodic maintenance is required to prevent machine breakdowns and to repair problems that cause failures to occur. Management may decide to save money by locking some wheels in the "lemon" position. Obviously, more people would be willing to play a machine in good working order than one in disrepair, and more people would be willing to play a machine whose status could be determined immediately before play than a machine whose condition is unknown.

- **Do all the wheels spin independently?** A multiwheel machine appears to offer more layers of protection than a single-wheel machine. However, there may be common-cause failure mechanisms (e.g., same manufacturer, power supply, location, or maintenance) that effectively lock two (or more) of the wheels together. Thus, if one wheel stops on "lemon," one (or more) of the other wheels will also stop there. People will prefer a machine with independent wheels over one whose wheels are interlinked.

Answers to the four questions above allow you to calculate the odds of death if you play the slot machine. Some people initially willing to play the game now decide they are not willing to play. Others, however, need more information before deciding.

- **Are the consequences immediate?** The prospect of immediate death is more daunting than death at some later time. The longer death is deferred, the more likely something else (e.g., old age) may cause death anyway. Advances in medical technology may render a currently fatal injury/disease survivable in the future. So, more people are willing to play a machine with delayed consequences than one with immediate consequences.

- **Whose death results from the bad spin?** It seems only fair that the person taking the risk should suffer the consequences of losing the gamble. If others are at risk, the acceptability of the gamble changes. People would generally be less willing to play a machine if it killed their children rather than themselves on a losing spin. On the other hand, people are more willing to play if the potential fatality is a faceless stranger with whom they have no personal connection.

- **What is the benefit of playing?** Even with a complete understanding of risk, the prospect of being rewarded influences people's acceptance of the risk. If there were no payout for non-lemon spins, few would play the machine. If all non-lemon spins paid $1 million, more people would play. If all non-lemon spins paid $1 billion, even more people would play. If all non-lemon spins paid a random amount ranging from zero to $1 billion, some people would play, based on their personal expectation of an "average" payout.

- **Have there been previous incidents?** The charred remains of a previous player would undoubtedly give pause to the most eager volunteer. Conversely, watching previous players haul buckets of money away would embolden others to play in the false belief that bad things won't (or can't) happen to them. The success experienced by previous players does not "prove" there is no danger. In fact, a careful observer should note how often players were paid for near-miss spins of lemons on all but one or two wheels. Such spins may indicate that the machine is malfunctioning or that the odds are worse than you thought. Even a machine working perfectly will randomly kill a player from time to time. Nevertheless, more people will play a machine that paid its previous player than one that fried its previous player.

Considering the answers to these questions, you must now decide whether to play the slots. You understand the likelihood of various outcomes and the severity of both positive and negative consequences. Accept the risk or get off the stage.

"TAKE ME TO THE REAL WORLD! BUT IS IT SAFER?"

Consider the following real-world situation. A chemical process contains a reactor that produces a proprietary material by reacting chlorine with a caustic solution. The reactor normally operates at atmospheric conditions, and the reactor is vented to a scrubber to remove any excess chlorine. During the chlorination, operators are required to periodically take a sample from the surface of the liquid slurry in the reactor. A hatch is typically left open on top of the reactor to (1) allow taking of the sample and (2) provide plenty of air flow during continuous venting of the reactor. This is a small operation, and there is only one operator in the chlorination control room during each shift.

The key accident scenarios of interest are (1) over-chlorination, which will drive the pH low enough to start a decomposition of the product in the reactor, and (2) low level in the reactor, which will allow chlorine to escape (unreacted) to the atmosphere. Even worse, if scenario number one occurs, the decomposition will start at the bottom of the reactor (where the chlorine enters), and the decomposition gases formed (essentially a chlorine gas bubble) will quickly lift almost all of the slurry out of the reactor (into the scrubber and out the open hatch into the process building), resulting in the low-level scenario (number two). Since operators may be near by (or on the floor below) when an over-chlorination occurs, the resulting consequences could be quite severe, possibly even fatal.

The company has many safeguards against these scenarios. A pH sensor and an oxidation-reduction sensor continuously monitor the degree of chlorination, and the operator periodically (twice each hour) performs a direct titration on a sample drawn from the reactor (to verify the calibration of sensors, which tend to drift). The operator performs other tasks, besides sampling, near the open hatch. The chlorine flow to the reactor can be stopped quickly by closing a manual quarter-turn valve at the reactor or by closing a remotely actuated valve from the control room. The chlorine spargers inside the reactor are visually checked every 3 months to help ensure even distribution of chlorine in the bottom of the reactor (to reduce the chance of localized over-chlorination). There are chlorine gas detectors within the building near the reactors; and these are checked and calibrated every month. The control room is kept under positive pressure using air drawn from the roof of the facility (three stories above the room). All employees working in the area (the shift chlorination operator, support personnel who may be visiting, maintenance personnel, etc.) are required to have escape respirators with them at all times, and operators are required to wear full-face respirators when taking samples through the hatch and any other time they are working near the hatch of the reactor. Finally, there is rigorous training, including drills twice each year, on emergency shutdown procedures, evacuation, and rescue.

The average pay for a chlorination operator (the employee who is primarily at risk) is between $25 and $40 per hour. The plant is nonunion and is located in a very rural area where this is one of the highest paid jobs in the area. The company has been one of the most stable employers for the past 20 years.

You find out that the company is hiring a chlorination operator. Now, assuming you were 20 years old, lived nearby, needed a job, and wanted to work in a production setting, would you PLAY THE GAME (take the job) if offered to you? Having trouble deciding? Well, then let's break the problem down into more bite-size pieces to help make the decision easier. And for illustration purposes, think about the problem in terms of the Killer Slot Machine.

First, consider the possible negative consequences (ZAP!!) if you get a PAY LINE with all lemons: Chemical pneumonia, poisoning, or asphyxiation caused by inhaling a large breath of chlorine. Note that chlorine can be quickly lethal at concentrations above 50 ppm in air, unless medical attention is prompt and effective.

Next, consider the possible positive consequences ($$$!!) if you get a PAY LINE with less than all lemons: A day's wage of at least $200! Cool! But, is there one "pull" of the handle each day? Two each day? That depends on the number of possible initiating events each day, which is tough to estimate without considerably more data and evaluation. Let's assume we perform the analysis. We determine that the number of pulls each day is about 20, based primarily on the number of times we are potentially exposed to a lethal breath of chlorine, which we estimate to be the 20 times we are near the open hatch of the reactor to take a sample and make other adjustments to the chlorinator during each 8-hour shift. (There are many other exposure scenarios, including over-chlorination while you're not near the hatch, a leaking or broken pipe, etc. We are going to assume those additional risks are negligibly small.) Based on 20 pulls per shift and wages of $200 per shift, the average payout per pull of the slot machine handle is at least $10 (pay received for vacations, holidays, process downtime, etc., increases the actual payout to about $11 per pull). There are approximately 47 workweeks for new operators, with an average 5-day workweek, so YOU will get to pull the handle on this slot machine about 4,700 times each year!

Next, consider the odds of each consequence: Before you decide to play (i.e., before you take the job), you probably want to know the likelihood of the negative consequences per pull, right? To estimate this, you need to determine how may "wheels" are on the slot machine and the likelihood of getting a lemon on each "wheel." Based on the information given, Table 1 is a summary of the "wheels" and “lemons” analysis of one specific accident scenario, which (as you will recall from event tree basics) is one pathway from initiating event through safeguard success or failures to a specific consequence.

Table 1 Percentage of Lemons on the Initiating Event and Safeguard Wheels

Wheel	Description	% Lemons on This Wheel
1 (Initiating Event)	Automatic sensors prevent over-chlorination, assuming good sparging and considering the titration by operators to check the calibration. Failure of this control system is the most likely initiating event	0.0005% (Probability = 5E-6) This is based on a failure rate of 1 over-chlorination every 2 years, 350 total operating days a year, and 5 minutes exposure per sample or batch adjustment
	Uneven distribution from the sparger can cause a localized pocket of material to over-chlorinate, triggering the remainder of the reactor to decompose as well. Failure of the sparger is the second most likely initiating event	
2 (Safeguard)	Annunciation by chlorine gas detectors will alert you to a large release of chlorine (this will allow you to take action to limit the chlorine release and evacuate)	100% (Probability = 1.0) This safeguard applies only when you are on a different floor or when you are on the reactor floor but are not taking a sample at the time of the release
3 (Safeguard)	Quick shutdown of the chlorine feed to the reactor will limit the release	100% (Probability = 1.0) This safeguard protects others, not you. With only an escape respirator within arm’s reach (or already on), most operators would run for the door and try to find a way to shut off the chlorine flow from outside the building
4 (Safeguard)	A personal respirator will protect you for a few minutes. You should wear it each time you take a sample or do other work near the hatch. You must wear it correctly to get a good seal each time	5% (Probability = 5E-2) There are many reasons or excuses why you might not wear your respirator as prescribed
5 (Safeguard)	Effective rescue may save you if you are not wearing your respirator and the release occurs while you are near the hatch	80% (Probability = 8E-1) If your respirator fails, you will probably die before rescuers can help you

Finally, determine the overall payout and odds: Even though the preceding arguments are over-simplifications for the sake of this example, you must nevertheless make the decision about accepting the job offer before the offer is withdrawn. The bottom-line odds for this particular slot machine are summarized in Table 2.

Table 2 Summary of Risk Considerations in Accepting the Job Offer

Description of Risk Factor	Risk Factor Per Pull of Handle	Risk Factor Per Person-year (4,700 pulls)
1. Chances of an event that could result in a catastrophic release of chlorine from the reactor (**unmitigated negative risk**)	Probability = 0.0005% or 5E-6 (Not too bad) (Odds of a lemon on Wheel 1)	Probability = 2.35% or 2.35E-2 (Pretty serious risk factor, but this is mitigated by safeguards as described below)
2. Chances of not surviving the large release, given the release does occur (**mitigation factors**)	Probability = 4% or 4E-2 (Combined odds of lemons on both Wheel 4 and Wheel 5)	Probability = 4% or 4E-2 (Combined odds of lemons on both Wheel 4 and Wheel 5)
3. **Mitigated risk of negative consequence**	Probability = 0.00002% or 2E-7	Probability ≈ 0.1% or 1E-3
4. **Chances of getting paid**	Probability ≈ 100% or 1.0	Probability ≈ 100% or 1.0
5. **Pay**	at least $10	$52,000 to $83,200 (With fringe benefits, but without overtime pay or other incentives)

So, with the prospect of working 40 years until retirement, you will have a 4% chance of dying by this accident scenario. If you play and win, you will earn about $3 million during that time. Otherwise, your family will probably receive a hefty settlement (at least in U.S. courts), your life insurance benefits, and a percentage of your earnings, although they will lose you!

Now decide: Will you play? I'd take the job! What if there were five chlorination reactors you had to simultaneously operate? Would you still play? Maybe. What if you evaluate the many other killer slot machine outcomes during a work shift and the cumulative risk from all the machines is five times higher. Would you still play? Hmm, maybe you'd need more safeguards.

A couple more questions: If you were on the hazard review team for this process, would you recommend additional safeguards for the over-chlorination scenario? As an operator, I probably would if I thought it wouldn't cost too much (such as getting the most reliable style of escape respirator available). As a manager representing the interest of the company, I'd refer to my company's risk tolerance criteria and would also evaluate other risk factors pertaining to the chlorination operators. In the end, I'd probably try to redesign the chlorinator to keep the lid closed. Also, the other employees (and I) would benefit from a chlorine shutoff valve that could be actuated from various locations other than the control room.

Closing observations on this example: The statistics listed above are optimistic "guesstimates," and your day-to-day risk will vary widely depending on significant personal factors and work situation factors. Also, there are many other accident scenarios in this plant, although this was the predominant large release scenario. However, my risk of dying (fatalities per hour) due to any work-related activity in this plant is lower than my risk of dying in typical nonwork-related activities. So, if this game appears safer than other alternatives currently available (considering the rewards), I'd go ahead and play! But, as a manager, I'd add more safeguards before allowing operators to play the game!

CONCLUSION

In the real world, of course, the slot machine we described does not exist, per se. Instead, there is the time clock that workers punch each day with the expectation of receiving a day's wage. But, there is some chance that they or someone else will be severely injured or killed as a result of "playing the game." If you are a designer, manager, or hazard analyst, your job is to ensure that those playing the machine know the odds and are involved in suggesting ways to improve the odds. Before we deem a process "safe enough," we should first examine the design for inherent safety — can the worst-case consequences be reduced (i.e., can we reduce the amperage and/or voltage of the mythical slot machine)? We next evaluate the design to see how many layers of protection there are against the consequences — are there enough wheels on the slot machine and do they all spin independently? We then evaluate the effectiveness of maintenance and operation in ensuring the integrity of each protective layer — what percentage of the wheel positions are lemons? And finally, we look at the management systems that ensure that the process design and operating limits are not compromised and that the organization's risk acceptance criteria are being enforced — are we buying machines with enough wheels, are there few enough lemons on the wheels we have, and are all the wheels spinning? So, next time your team or organization is struggling to decide whether the risk is acceptable, rephrase the question: Would you play the Killer Slot Machine?