

# **Ten Rules For Preparing Sensible Risk Assessments**

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## **1. Abstract**

FMEAs and Probability Impact Graphs (PIGs) can be useful in understanding at preliminary level the risks inherent in tailings facilities. Too often, however, PIGs are misused and the mistakes made give superficial and incorrect pictures of tailings facility risks. This paper describes some common mistakes made in the use of PIGs and suggests ways to avoid such mistakes.

## **2. Introduction**

FMEAs and Probability Impact Graphs (PIGs) do not grasp the complex story of the multi-hazard (or convergent) risks assessments that should be an integral part of responsible tailings management. PIGs present at best a colorful chart, usable as rough first estimate (NASA, 2007), but not for complex decision-making for critical infrastructures like tailings storage facilities. People often accept PIGs uncritically and trustingly until something goes wrong. Problems arise from the use of an unclear glossary, the basic structure of the hazard and risk register; continue with simplistic definition of probabilities and censored consequences. Experience has shown that PIGs often end with a major confidence crisis, possibly leading to societal or regulatory opposition (Chapman 2011, Cox 2008, Hubbard 2009).

This paper explores the idea that correcting a series of common mistakes, which can be done quite easily and inexpensively, would lead to honest and more representative way to assess tailings facilities risks.

### **3. The common missteps and their quick fix**

The missteps described below are a compilation of the most common pitfalls we have encountered while reviewing hundreds of Risk Assessment reports related to mining and other industrial activities around the world.

Each misstep is described with an example, and a quick fix is summarized.

#### **3.1 System definition**

**RULE 1:** always use a well-defined technical glossary, throughout the study. Do not accept improper, unclear definitions. Do not try to guess the meaning of other team members.

**Misstep example:** We have heard people talking about “risk” as a synonym for probability or hazard. This becomes extremely confusing when modeling a system and discussing what are manageable/unmanageable risk and how to address them. Hazards, in short, are anything that can go wrong. Hazards have a probability of occurring and a consequence. Risks are hazards' probability\*consequence.

**Quick fix:** Always base your assessment on a well-defined glossary, for example see <http://www.riskope.com/knowledge-centre/tool-box/glossary/>. There are many others.

**RULE 2:** Always perform a functional analysis (as is required, but very seldom performed, when starting a FMEA study). Be sure to take into account cascading failures and inter-systems interdependencies. The definition of the success/failure criteria is fundamental to understand both the hazard and the system.

**Misstep example:** Put together a risk register without defining the system's functional analysis, success/failure criteria (Fig. 1,2). Consider self-sufficient engineering systems forgetting their interactions with other systems/subsystems, the environment and the world.

The largest and costliest mistakes are generally made when (poorly) defining the system. You have to understand the context of the study and what constitutes the system you have to assess.

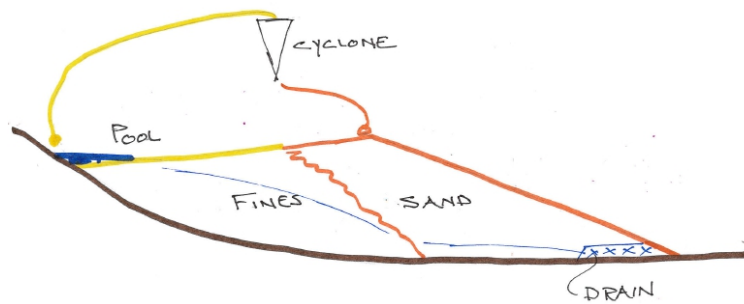


Fig. 1 A classic sketch of a tailings cyclone system presented for a preliminary risk assessment: tailings distribution line (from the mill), slime system, decant barge in the pool are not shown and will most likely be forgotten in the hazard and risk register.

**Quick fix:** Determine the limit of the system and the logical connections between the components. Then state why inclusions/rejections decisions are made as part of increasing study's transparency.

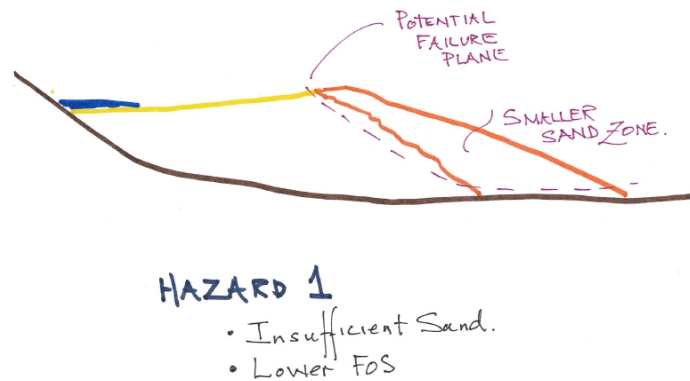


Fig. 2 Following the idea of Fig. 1 the preliminary study indicated insufficient sand and lower Factor of Safety (FoS) as Hazards. Insufficient sand is the consequence of some occurrence/upset “upstream”, so it is not a hazard. Likewise, lower FoS is also a consequence. By confusing hazard and consequence the risk register will start to be logically inconsistent and results will be misleading.

**RULE 3:** Always start by identifying hazards using threats-to and threats-from. Perform strong logic checks on your risks definitions.

**Misstep example:** Starting the RM process by brainstorming all possible risks with the crews, without proper preparation, most of the time leads to mislabel hazards or concerns as “risks” (see Rule 1) (Fig. 3).

**Quick fix:** The Hazard Identification process is an important step, but not the first one. Only once all the logical connections are established can one be sure that you have been as methodical and exhaustive as possible.

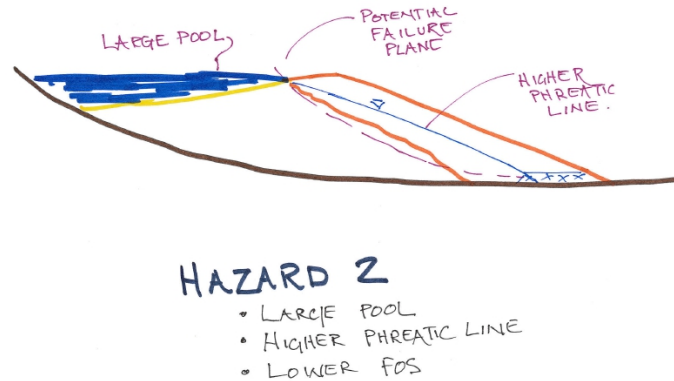


Fig. 3 Following the prior two figures case history: the large pool is not a hazard, but, again the consequence of something happening upstream.

In the case of Fig. 3 the large pool event could be linked to elements that were left aside in Fig. 1, such as, for example, decant barge chronically malfunctioning, or natural hazards such as adverse climatic cycles and poor diversion channels at the perimeter (which was not properly defined in the example above). The threat-to, threat-from analysis would significantly help to perform a proper analysis, should the system have been described properly.

**RULE 4:** Check your risk statements (record per record in your hazard and risk register) to avoid double counting.

**Misstep example:** If in a risk register a hazard is listed without a “threat-to” it is impossible to assess its consequences (Fig. 4,5).

The same hazard can lead to definition of a widely different risk because the consequences may vary in time and location. For example the hazard “traffic accident” will have different consequence depending on what it is impinging on and what generates it (construction equipment hits pipeline, snow removal knocks out a data telemetry station, etc.) .

**Quick fix:** Always link a hazard to a component of the system. If various hazards can hit the same component, or if the same hazard can hit many components, each one of them has its own line in the hazard register.

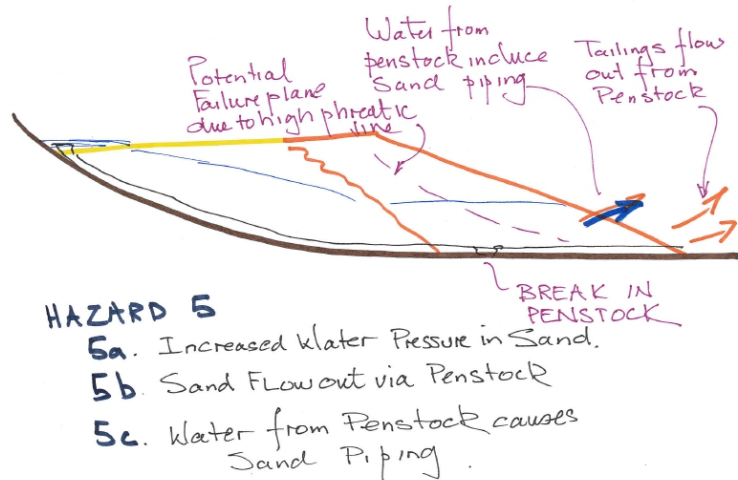


Fig. 4 Unless properly specified by working a robust logic into the hazard and risk register, many of the elements shown in this figure lead to double counting of consequences and then risks.

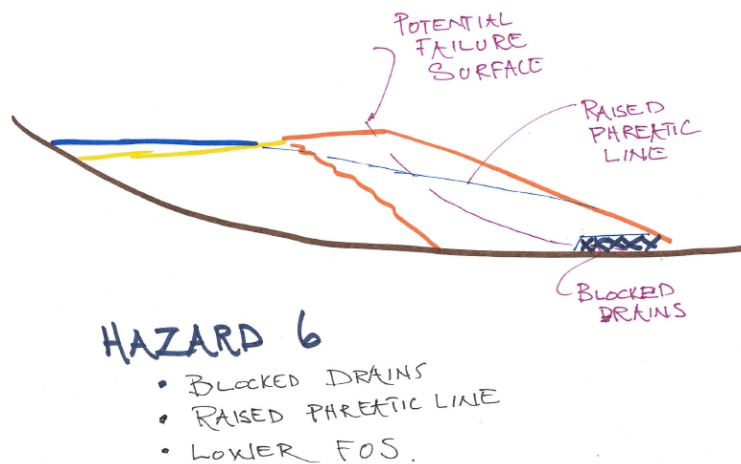


Fig. 5 The blocked drain can be the effect of dam's settlement, chemistry etc. Without a proper Threat-to, threat-from confusion and double counting will arise.

### 3.2 Probabilities and Consequences

*It is better to be roughly right than precisely wrong.*

—John Maynard Keynes

**RULE 5:** Always consider a range of probabilities in order to include the range of uncertainties.

**Misstep example:** Giving one precise value for the probability.

The past can never be assumed to equal the future. At best it can be used as a point estimate.

**Quick fix:** Uncertainties will always exist. Consider the limits of our human capability to estimate events. Give one pessimistic probability, possibly Common Cause Failure based (i.e. in the case all

redundancies fail because of a common flaw), and one optimistic probability with the foreseen mitigation active. If probabilities are transparently considered uncertain, then a Bayesian update mechanism can be implemented when new data become available (NASA 2009).

**RULE 6:** Always consider a range of consequences.

**Misstep example:** Giving one precise value for the consequences. The human brain is generally good at imagining the best and the worst scenario but we see many times that people censor the range considered.

In modern society, he who hides risks dies, sooner or later.

**Quick fix:** Uncertainties will always exist. Don't censor!

**RULE 7:** The consequences are almost always a mix of those associated with health and safety (H&S), Business Interruption (BI), environmental, etc. at least in an additive way (MRVEIB 2012).

**Misstep example:** The consequences of a small car accident is that you arrived late AND you have some repair to make AND you might be bruised. Why is it that consequences of a facility evaluation often consider only the “worst” among, for example, H&S or environmental or BI?

**Quick fix:** Record all types of consequences and then work with a blended metric.

### 3.3 PIGs and their hidden faults

**RULE 8:** When using a risk matrix (Probability Impact Graph, PIG) for the risk prioritization (usually stated as a specific color) there is the need to check that the colors “match” real life (corporate or societal) expectations.

Probability				
	Impact			

**Misstep example:** PIGs are usually drawn symmetrically, or almost symmetrically, in such a way that high consequence, low probability events have the same risk “color” as low consequence, high probability events. Would you say it is fair to say that the risk of an asteroid obliterating your house (and family) is prioritized in the same way as you getting a cold as the PIG above suggests?

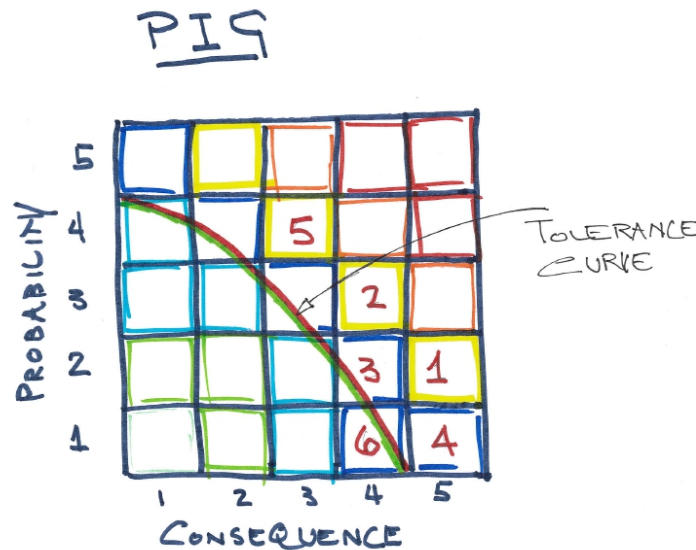


Fig. 6 “instinct” or “intuition” are often poor advisors when attempting to define a risk tolerance threshold to replace the arbitrary PIGs (risk matrix) colouring.

Fig. 6 shows an attempt to diverge from a PIGs color scheme, but the minimum consequence-maximum probability show again the same risk priority as minimum probability-maximum consequence. This is obviously, again incorrect as it says that the worst case should be prioritized equally as the most likely (and benign) risk.

Also #1, #2 and #5 have the same PIG-based color risk prioritization which are greater than #3 and #4 whereas # 6 has the lowest priority (Fig. 6).

As reviewers we would question why hazard #5 is binned with a consequence index 3 while all the other hazards are binned either 4 or 5. Is it inconceivable (for which reason) that hazard #5 would have a larger consequence and was it “mis-binned”, biasing the results? Was this the case of consequence censoring and biasing under conflict of interest or complacency pressure (Oboni 2013)

**Quick fix:** Use extreme cases to see if it still make sense. If you really have to use the PIGs representation alter the coloring scheme until it makes sense. Do not try to guess a tolerance threshold: there are specific studies required to develop a defensible one.

**RULE 9:** Do not bin.

**Misstep example:** Develop classes for the Consequences and Probabilities for your risk prioritization. It is not by adding another color or class that you will solve the binning systemic error (Fig. 6).

**Quick fix:** Above all, avoid using indices. Stay quantitative. The maths are simple and the risk assessment will be tremendously improved if your “risk-dots” are in the proper p,C position and not just

binned in. This fix will allow for rational prioritization but also enable providing insurance limits computations and avoid being overwhelmed by bin-overcrowding.

**RULE 10:** Use published societal Tolerance thresholds (Fig. 7) to see where you are standing, and develop your own tolerance criteria for corporate affairs.

**Misstep example:** Coloring schemes or thresholds criteria mismatch with accepted thresholds. We have seen risk assessment rejected because they were not defensible at that level (Fig. 8).

Tolerability has to be defined in order to allow proper decision making.

Tolerability definition requires transparent communication with stakeholders.

**Quick fix:** Do not use prefabricated PIGs with arbitrary cell limits definitions or arbitrary colors. You do not need the cells! And you can put in your plot a well thought-out tolerance limit.

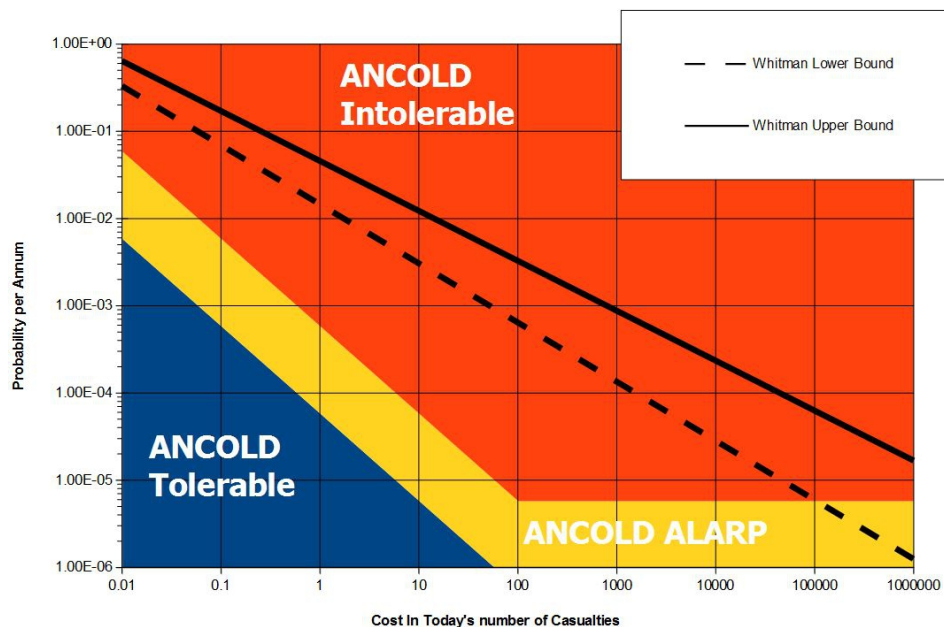


Fig. 7. ANCOLD and Whitman published tolerance thresholds. (ANCOLD 2003) (Whitman 1984)



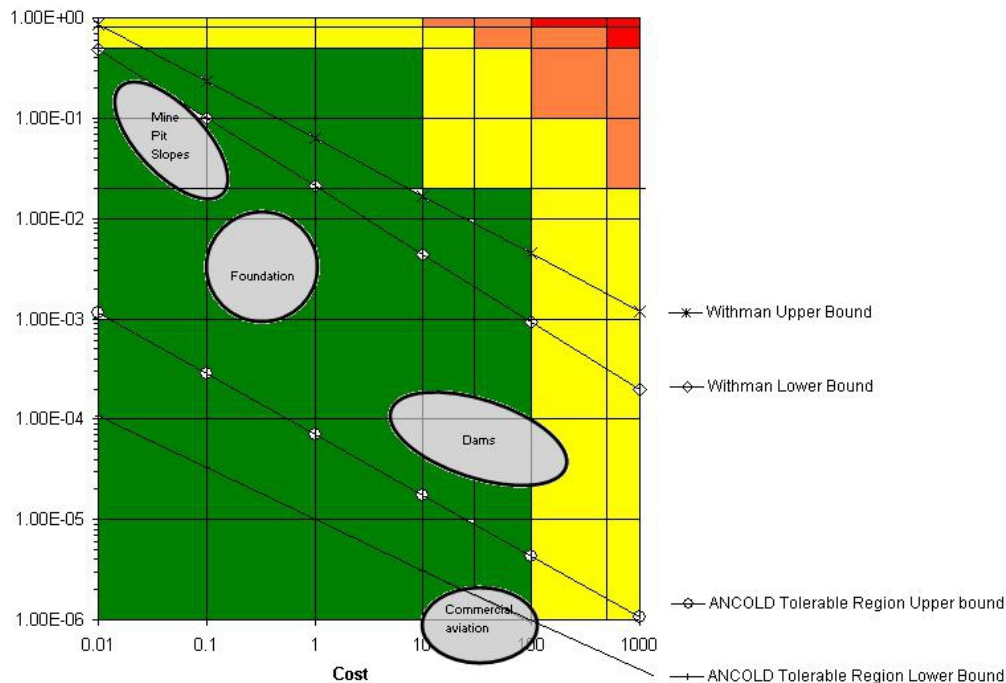


Fig.8 A coloured risk matrix superimposed over ANCOLD and Whitman's thresholds. One can see that the green coloured cell are in the intolerable part of both Whitman's and ANCOLD which, in the case of a mishaps, would prove difficult to defend. One day such a case will end up in a Court of Law: will it be negligence? Or mis-representation to the public, victims? In the case of 2009 L'Aquila earthquake, convictions were initially based on poor risk communication, and more broadly, about the responsibility scientists have as citizens to share their expertise in order to help people make informed and healthy choices (Ropeik 2012).

#### 4. Specific thoughts about Tailings Dams

In the prior sections of this paper we have dealt with ten rules for better risk assessments, have stated that indexed approaches should be abandoned and “true” values of  $p, C$  should be used. In this last section we are going to show how ranges of probabilities can be defined at preliminary level.

As per the consequences, they should be dealt following the failure criteria developed in rule #2, for each project/case.

The starting point of the preliminary probability analysis can be the 2008 Silva, Lambe, and Marr paper that we have used in many occasions (Silva, 2008) as a preliminary basis in cases where we need to define a “starting point” for the probability of failure ( $pf$ ) accounting for the care of construction and the extent of, monitoring and preservation of the structure.

Of course, values of  $pf$  (stability) can be estimated using modelling approaches of increasing levels of sophistication:

1. Consider the Factor of Safety a stochastic variable, for which the members of the assessing team define the expected value, min, max (either subjectively or from various analyses, or both) and then  $pf(\text{stability})$  which is hopefully calculated to be less than one, i.e.,  $p(\text{FoS} \leq 1)$ .
2. Use point estimates methods to define the variability of the FoS and then  $pf(\text{stability})$  is again hopefully calculated as  $p(\text{FoS} \leq 1)$ .
3. Use probabilistic stability analysis methods like (Oboni, Bourdeau, Bonnard, 1984).

After defining the  $pf$  (stability), which should include uncertainties regarding the material, and construction care and design, an Event Tree Analysis (ETA) can be constructed to account for monitoring and maintenance, leading to  $pf$ .

The  $pf(\text{stability})$  is the starting point of the ETA. Monitoring, repairs, etc... come in as branches.

- Methods 1 and 2 plus the ETA give a good estimate of the  $pf$ .
- Method 3 + ETA is even better, but is generally reserved to very critical cases because it requires new slope stability analyses.

Now, we will use a poor quality generic mine TSF as a case history (it is a real case, made anonymous). A site visit and survey allowed to detect the following:

- Slopes were slightly steeper than designed.
- Cracks were present nearby the Eastern abutment.
- There was a settlement monitoring system, but there was limited information on the readings, frequency, etc.
- There was locally uncontrolled erosion of the downstream slope.

The consequence analysis should include in this particular case history: mine access road destruction (including a bridge), mine business interruption, and narrow valley flooding.

#### **4.1 Preliminary framing of $pf$ using Silva Lambe Marr.**

Due to the observations noted the dam could be categorized as Category IV or, at best, III.

Extant stability analyses gave factors of safety ranging between 1.3 and 1.5 which, incidentally could be accepted as “good values” for the dam (neglecting existing unrepaired damages).

If we use those values and the Silva, Lambe, Marr curves we obtain a set of estimates shown in the table below.

	<b>Class III</b>	<b>Class IV</b>
<b>Fos=1.5</b>	pf= $10^{-2}$ (1%)	pf= $10^{-1}$ (10%)
<b>FoS=1.3</b>	pf= $3 \cdot 10^{-2}$ (3%)	pf= $3 \cdot 10^{-1}$ (30%)

Let's consider these values of pf as a very rough first approximation.

## 4.2 Approach N.1.

The same extant stability analyses enabled us to determine that the average of the FoS lies between 1.32 and 1.36, with a coefficient of variation driven mostly by the granular nature of the soils, thus 15% to 20%.

<b>Average</b>	<b>C.O.V 15%</b>	<b>C.O.V 20%</b>
<b>Fos=1.36</b>	pf= $3.8 \cdot 10^{-2}$ (3.8%)	pf= $10^{-1}$ (10%)
<b>FoS=1.32</b>	pf= $5.3 \cdot 10^{-2}$ (5.3%)	pf= $11 \cdot 10^{-1}$ (11%)

We note that both methods give comparable estimates of the order of magnitude of the pf, and that the second one, as it should, reduces, with a minimal additional effort, the range of the pf estimates. At this point we could build a ETA to complete the analysis of the case. We note that this structure has incredibly high probability of failure, say hundred times larger than the world portfolio (Oboni, Oboni, 2013).

So, at the end of the day, you can see that by using a blended approach we can:

- Swiftly frame the problem and
- Allow the discussion related to the “homogeneity” of the considered slope.

If we were to add the effects of monitoring and maintenance (almost in-existent here) by using an ETA the final probability range would not change much from the Approach N.1, in this particular case.

The newly calculated pf range could then be introduced into the FMEA together with well thought out multi-dimensional consequences.

## 5. Conclusions

Use of PIGs is widespread in the mining industry. Used with care and consideration, they may be useful tools in understanding and managing, at least at preliminary level, the risks inherent in tailings facilities.

Used incorrectly, PIGs may simply mislead managers and even contribute to tailings failure. BHP claimed the day after the failure of Samarco that they used PIGs to manage the risks of Samarco. We have heard no more from them on the topic.

This paper notes common mistake often made when using PIGs and suggest remedies. Hopefully the guidance helps.

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