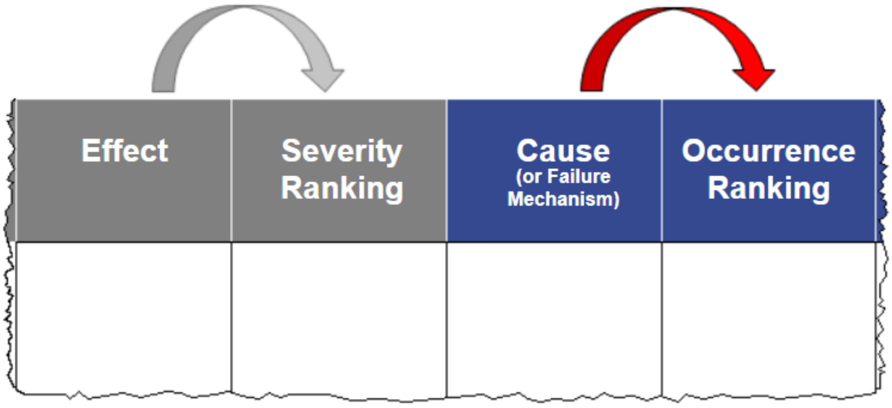
Laboratory 5

STEP 5 - Assign Occurrence Rankings

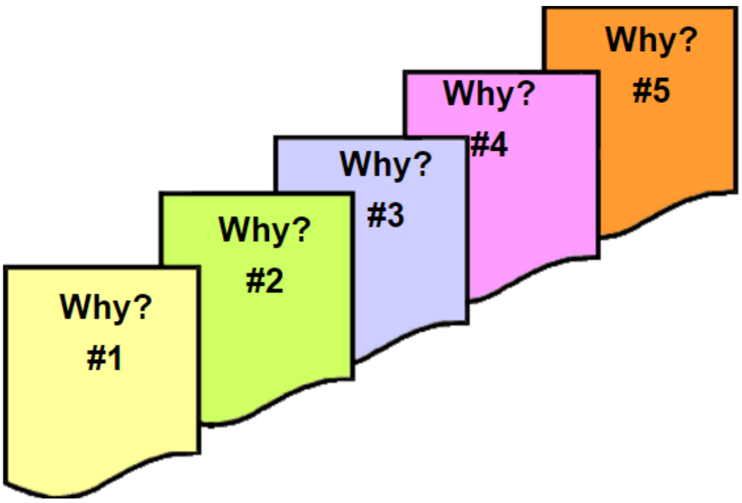
Now we're ready to move onto Step 5 where we will consider the potential cause or failure mechanism for each failure mode and then we will assign an occurrence ranking to each of those causes or failure mechanisms.

We need to know the potential cause to determine the occurrence ranking because, just like the severity ranking is driven by the effect, the occurrence ranking is a function of the cause. The occurrence ranking is based on the likelihood, or frequency, that the cause (or mechanism of failure) will occur.



If we know the cause, we can better identify how frequently a specific mode of failure will occur. How do you find the root cause? There are many problem-finding and problem-solving methodologies. One of the most powerful and easiest to use is the 5-Whys technique.

To use the 5-Whys technique, ask "Why?" a failure occurred. The answer to the first "Why?" is almost always an obvious symptom. The secret behind the 5-Whys technique is to accept the answer, but to then ask "Why?" again and again until the root cause is uncovered.



Example:

Why-1: Why did the automobile stop?
Answer: Because the automobile's engine stopped running.

Why-2: Why did the engine stop running?
Answer: Because the engine overheated.

Why-3: Why did the engine overheat?
Answer: Because the coolant leaked from the radiator.

Why-4: Why did the coolant leak from the radiator?
Answer: Because the coolant hose clamp broke.

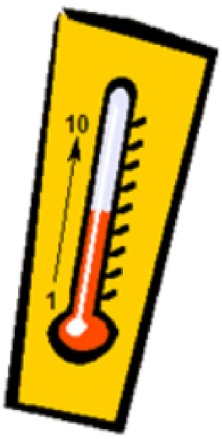
Why-5: Why did the hose clamp break?
Answer: Because the wrong style clamp was used.

Why-6: Why was the wrong style clamp used?
Answer: Because the installation documentation was unclear.

...And, "Why-7" and perhaps "Why-8" will eventually lead to the root cause.

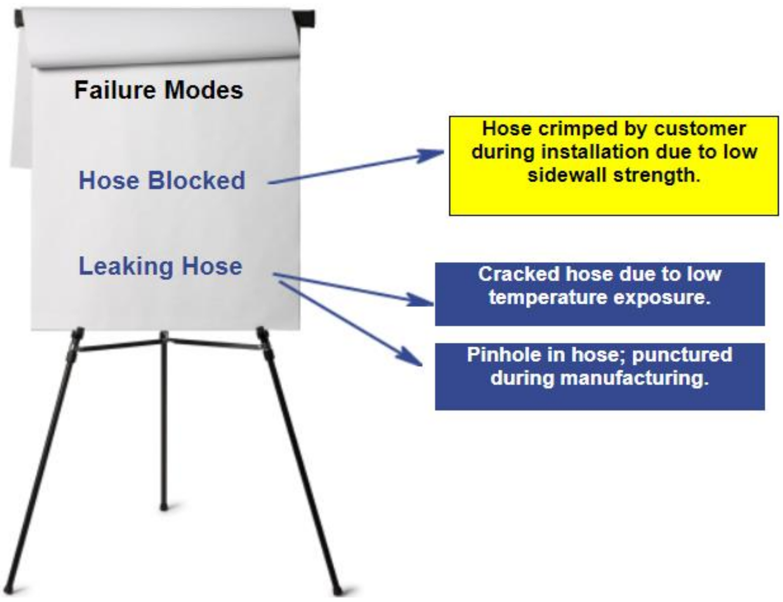
Once a cause is known, capture data on the frequency of the causes. Sources of data may include scrap and rework reports, customer complaints, and equipment maintenance records. If data do not exist, estimate the frequency of occurrence using either data from a similar product or using the skills and knowledge of the team members.

The occurrence ranking scale, like the severity ranking, is on a relative scale from 1 to 10. An occurrence ranking of 10 means the failure mode occurrence is very high and happens all of the time. Conversely, a 1 means the probability of occurrence is remote. The scales provide a relative, not an absolute scale. For now, we'll use the brief descriptions here.



10 = Very High: Failure happens almost all the time
9 = High: Failures occur almost as often as not
8 = High: Repeated failures
7 = High: Failures occur often
6 = Moderately High: Frequent failures
5 = Moderate: Occasional failures
4 = Moderately Low: Infrequent failures
3 = Low: Relatively few failures
2 = Low: Failures are few and far between
1 = Remote: Failure is unlikely

Using our simple washing machine example, the potential causes of the corresponding failure modes are listed.



The relative occurrence rating for the potential causes of the failure modes for our washing machine hose are shown. In this case, the team had several years of data on similar products which was found in both manufacturing records and customer history files.

Potential Cause	Occurrence Ranking
Hose crimped by customer during installation due to low sidewall strength.	4
Cracked hose due to low temperature exposure.	3
Pinhole in hose; punctured during manufacturing.	2

Failure Mode	Effect(s)	Sev	Cause(s)	Occ
Hose blocked	No water flow	6	Hose crimped	4
	Low water flow; long cycle	3		4
	Premature pump failure	7		4
Leaking hose	Large water spill; ruin customer's floor; angry customer	10	Cracked hose	3
		10	Pinhole	2
	Small water leak; slippery condition; dissatisfied customer	9	Cracked hose	3
		9	Pinhole	2

The potential causes and occurrence ratings of the failure modes for the washing machine hose have been added to the appropriate columns of the DFMEA Worksheet.

Let's take a look at customizing the scales for a DFMEA. Remember, we have three sets of ranking scales: one scale for severity, one for occurrence, and one for detection. We'll look at the occurrence scale now.

This is a recap of the AIAG "Suggested DFMEA Occurrence Evaluation Criteria." We'll use this as the starting point for customizing occurrence scales. For many organizations, this scale must be customized as the likely failure rate column shown here reflects a high-volume manufacturing environment.

Likelihood of Failure	Criteria: Occurrence of Causes – DFMEA (Design life/reliability of item/vehicle)	Incidents per item/vehicle	Rank
Very High	New technology/new design with no history.	≥ 100 per thousand ≥ 1 in 10	10
High	Failure is inevitable with new design, new application, or change in duty cycle/operating conditions.	50 per thousand 1 in 20	9
	Failure is likely with new design, new application, or change in duty cycle/operating conditions.	20 per thousand 1 in 50	8
	Failure is uncertain with new design, new application, or change in duty cycle/operating conditions.	10 per thousand 1 in 100	7
Moderate	Frequent failures associated with similar designs or in design simulation and testing.	2 per thousand 1 in 500	6
	Occasional failures associated with similar designs or in design simulation and testing.	0.5 per thousand 1 in 2,000	5
	Isolated failures associated with similar designs or in design simulation and testing.	0.1 per thousand 1 in 10,000	4
Low	Only isolated failures associated with almost identical design or in design simulation and testing.	0.01 per thousand 1 in 100,000	3
	No observed failures associated with almost identical design or in design simulation and testing.	≤0.001 per thousand 1 in 1,000,000	2
Very Low	Failure is eliminated through preventive control.	Failure is eliminated through preventive control.	1

Some organizations have developed three different occurrence ranking options and select the option that applies to the design or product. Remember, the level for each of the rows should be roughly equal from a relative standpoint.

Ranking	Occurrence: Time-Based Examples
10	≥2 occurrence per day
9	≥1 occurrence per day
8	≥1 per 2 to 3 days
7	≥1 per week
6	≥1 per 2 weeks
5	≥1 per month
4	≥1 per quarter
3	≥1 per half-year
2	≥1 per year
1	<1 per 1 year

Ranking	Occurrence: Event-Based Examples
10	≥5 per design
9	≥2
8	≥1
7	≥1:2 designs
6	≥1:5
5	≥1:10
4	≥1:50
3	≥1:100
2	≥1:250
1	<1:250

Ranking	Occurrence: Piece-Based Examples
10	$C_{pk} < 0.33$
9	$C_{pk} \approx 0.33$
8	$C_{pk} \approx 0.67$
7	$C_{pk} \approx 0.83$
6	$C_{pk} \approx 1.00$
5	$C_{pk} \approx 1.17$
4	$C_{pk} \approx 1.33$
3	$C_{pk} \approx 1.67$
2	$C_{pk} \approx 2.00$
1	$C_{pk} > 2.00$

STEP 6 - Assign Detection Rankings

Think of the Detection Ranking as an evaluation of the ability of the design controls to prevent or detect the mechanism of failure. The evaluation criteria judge the probability that a failure mode will be prevented or detected before either the failure occurs, the mechanism of failure is triggered, or the effect is "felt" by the (internal or external) customer. Prevention controls are always preferred over detection controls.

Prevention controls prevent the cause or mechanism of failure or the failure mode itself from occurring; they generally impact the frequency of occurrence. Prevention controls come in different forms and levels of effectiveness.

Prevention Controls

- Robust Design Rules & Purchasing Controls.
- Design for Assembly/Manufacturability:
  - Use of asymmetrical shapes for mistake-proofing.
  - Self-aligning surface and guides.
  - Modular designs.
- Simulations such as:
  - FEA (finite element analysis).
  - Computer modeling.
- Supplier Involvement:
  - Because "you don't know what you don't know."

Detection controls detect the cause, the mechanism of failure, or the failure mode itself after the failure has occurred BUT before the product is released from the design stage. These are some examples of types of detection controls.

Detection Controls

- Design Reviews.
- Simulations ("after the design") such as:
  - Design validation tests.
  - Accelerated life tests.
- Verification steps such as:
  - Testing prototypes.
  - Alpha and Beta testing.
  - GO/NOGO Tests.

10 = Absolute uncertain
9 = Very remote
8 = Remote
7 = Very low
6 = Low
5 = Moderate
4 = Moderately high
3 = High
2 = Very High
1 = Almost certain

The detection ranking scale, like the severity and occurrence scales, is on a relative scale from 1 to 10. A detection ranking of 1 means the chance of detecting a failure is almost certain. Conversely, a 10 means the detection of a failure or mechanism of failure is absolutely uncertain.

As with the Severity and Occurrence Rankings, each level provides a relative, not an absolute scale. For the washing machine hose example, we'll use the brief descriptions for Detection Rankings shown here.

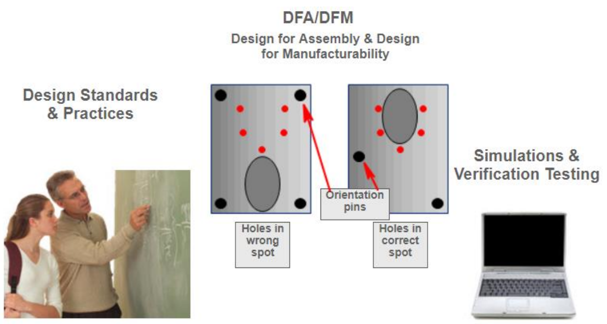
The relative detection ranking for the controls related to the failure modes for our washing machine example are shown. Note that two dramatically different detection rankings are shown for the "cracked hose" cause of failure. The in-process pressure test provides a relatively good detection ranking of 3. If, however, the discharge hose is subjected to cold weather during shipping or in-transit storage, the in-process controls are invalid. The customer would find the resulting leak only upon use.

Failure Mode	Effect	Cause	Prevention Controls	Detection Controls	Det
Hose blocked	No water flow	Hose crimped	Lab simulation	None	5
	Low water flow; long cycle				5
	Premature pump failure				5
Leaking hose	Large water spill; ruin customer's floor; angry customer	Cracked hose	None	None	10
			None	In-process pressure test	3

This is a recap of the AIAG "Suggested DFMEA Detection Evaluation Criteria." We'll use this as the starting point for customizing detection scales.

Opportunity for Detection	Criteria: Likelihood of Detection by Design Control	Rank	Likelihood of Detection
No detection opportunity	No current design control; Cannot detect or is not analyzed.	10	Almost Impossible
Not likely to detect at any stage	Design analysis/detection controls have a weak detection capability; Virtual Analysis (e.g., CAE, FEA, etc.) is **not correlated** to expected actual operating conditions.	9	Very Remote
Post Design Freeze and prior to launch	Product verification/validation after design freeze and prior to launch with **pass/fail** testing (Subsystem or system testing with acceptance criteria such as ride and handling, shipping evaluation, etc.).	8	Remote
	Product verification/validation after design freeze and prior to launch with **test to failure** testing (Subsystem or system testing until failure occurs, testing of system interactions, etc.).	7	Very Low
	Product verification/validation after design freeze and prior to launch with **degradation** testing (Subsystem or system testing after durability test, e.g., function check).	6	Low
Prior to Design Freeze	Product validation (reliability testing, development or validation tests) prior to design freeze using **pass/fail** testing (e.g., acceptance criteria for performance, function checks, etc.).	5	Moderate
	Product validation (reliability testing, development or validation tests) prior to design freeze using **test to failure** (e.g., until leaks, yields, cracks, etc.).	4	Moderately High
	Product validation (reliability testing, development or validation tests) prior to design freeze using **degradation** testing (e.g., data trends, before/after values, etc.).	3	High
Virtual Analysis - Correlated	Design analysis/detection controls have a strong detection capability; Virtual Analysis (e.g., CAE, FEA, etc.) is **highly correlated** with actual or expected operating conditions prior to design freeze.	2	Very High
Detection not applicable; Failure Prevention	Failure cause or failure mode cannot occur because it is fully prevented through design solutions (e.g., proven design standard, best practice or common material, etc.).	1	Almost Certain

To provide DFMEA teams with meaningful examples of Design Controls, consider adding examples tied to the Detection Ranking scale. Remember, the level for each of the rows should be roughly equal from a relative standpoint.



Ranking	Detection: Examples of Design Standards
10	No design standards used.
9	Design protocols and practices are formalized.
8	Design standards are specified in initial design criteria.
7	Design reviews held to ensure compliance to design standards.
6	Checklist used to ensure design standards are followed.
5	Purchasing systems do not allow selection of non-standard components.
4	Early supplier involvement to all relevant knowledge about input materials and compliance to design needs are understood.
3	Design software signals compliance issues.
2	Design software ensures compliance to the relevant standards.
1	Design software prevents use of non-standard dimensions, spacing, and tolerances.

Ranking	Detection: DFA/DFM Examples
10	No consideration given for DFA/DFM.
9	The number of components has been minimized.
8	Only standard components have been used.
7	Ergonomic assembly techniques have been incorporated.
6	Design elements such as pad sizes, wire gauge, and fasteners have been standardized throughout the design.
5	Modular designs used.
4	Easy-fastening devices (snap fits or quick fastening devices such as quarter-turn screw, twist locks, spring clips, latches) used.
3	Self-testing or self-diagnosis has been built-in.
2	Self-aligning surface, grooves, and guides used.
1	Asymmetrical features used to mistake-proof assembly.

Ranking	Detection: Simulation & Verification Examples
10	No verification testing used.
9	GO/NOGO tests used to ensure dimensional requirements.
8	Partial functionality of prototype tested before release.
7	Full Alpha tests conducted; no Beta testing.
6	Untested computer model used to simulate product performance.
5	Accelerated life testing of final design before release; lab simulation.
4	Alpha and Beta testing used before release to ensure design meets needs.
3	Product tested for full functionality in customer's application.
2	Finite element analysis to highlight stress concentrations requiring design changes early in the design stages.
1	Computer modeling to ensure form and fit of mating components.

STEP 7 - Calculate the RPNs

The RPN is the Risk Priority Number. The RPN gives us a relative risk ranking. The higher the RPN, the higher the risk.

The RPN is calculated by multiplying the three rankings together. Multiply the Severity Ranking times the Occurrence Ranking times the Detection Ranking. Calculate the RPN for each row on the DFMEA Analysis Worksheet. Since each of the three relative ranking scales ranges from 1 to 10, the RPN will always be between 1 and 1000. The higher the RPN, the higher the relative risk.

The RPN gives us an excellent tool to prioritize focused improvement efforts.

The calculations for the Risk Priority Numbers for the washing machine hose are shown. You can see that we multiplied the severity, occurrence, and detection ranking for each row to get the corresponding RPN.

Failure Mode	Effect	S	Cause	O	Control: Prev.	Control: Detect.	D	RPN
Hose blocked	No water flow	6	Hose crimped	4	Lab simulation	None	5	120
↓	Low water flow; long cycle	3	↓	4	↓	↓	5	60
↓	Premature pump failure	7	↓	4	↓	↓	5	140
Leaking hose	Large spill, ruin floor; angry customer	10	Hose cracked in transit	3	None	None	10	300
↓	↓	10	Hose cracked in assembly	3	↓	In-process press. test	3	90
↓	↓	10	Pinhole	2	None	In-process press. test	3	60
↓	Small water leak; slippery condition; dissatisfied customer	9	Hose cracked in transit	3	None	None	10	270
↓	↓	9	Hose cracked in assembly	3	↓	In-process press. test	3	81
↓	↓	9	Pinhole	2	None	In-process press. test	3	54