Improving Team Communication with Design Technology Readiness Levels

By: David G. Ullman

How “ready” are the technologies you are using in your new product?
Do you have a good understanding of the developmental distance to product release?
Does your team share this understanding?
Does your organization?
Do all the parties have a clear picture of the product development risks?

The history of “Technology Readiness.”

The Technology Readiness Level (TRL) scale was first developed at NASA in the 1970s to be a consistent measure of technology maturity. It is now widely used in the Department of Defense and by others to communicate how closely a technical system is to being useable. While this nine-level scale is very good at helping quantify maturity for a system, it is not totally suited to help during the product design process.

This NASA scale is the basis of the Design Technology Readiness Level (DTRL) assessment described in this article. It is the NASA tool tuned for product development. It was designed when working with a consulting customer who had weak communication between engineering and the other business units. Also, like any design team, there was a need to support communication within the team. Finally, there was a need for a clear way to identify and communicate product development risks. All of these issues were overcome using the DTRL method described here.

The starting place is the nine NASA levels, shown briefly in Figure 1.

NASA Technology Readiness Levels

TRL 1 Basic principles observed and reported

TRL 2 Technology concept and/or application formulated

TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 4 Component/subsystem validation in laboratory

TRL 5 System/subsystem/component validation in relevant environment

TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space)

TRL 7 System prototyping demonstration in an operational environment (ground or space)

TRL 8 Actual system completed and “mission qualified” through test and demonstration in an operational environment

TRL 9 Actual system “mission proven” through successful mission operations (ground or space)

Figure 1 NASA Technology Readiness Levels

Here, the lowest level, TRL 1, is where the technology is still in the laboratory but may have applications. Some people claim there is actually a Level 0 for technologies that have only been realized in dreams or the shower. Needless to say, TRL 0 and 1 technologies are far from being applied in a product, but they are the germ of an idea.
At the other end of the scale, TRL9 is a technology that is proven and in use.

When thinking of a “technology” for DTRL assessment, consider any science or technique that may be used in a product. The technologies can be functional, manufacturing, or any other topic requiring time and effort to develop during the design process.

The Design Technology Readiness Score

The Design Technology Readiness Score should be used to evaluate each critical technology in a product being developed. The scoring method is intended to aid in communication amongst groups and for them to be able to assess, from the beginning of a project or even before, the level of uncertainty or technical risk. Technical risk has direct implications for time-to-product and development costs.

Further, the scoring gives a clear indication of what to do before committing to the use of a technology in a product.

In general, the method should only be applied to critical or new technologies in a product. It is not very helpful for day-to-day technologies such as sheet metal forming, metal finishing, or PC board manufacture unless it relates to a type of forming, finishing, or manufacturing that is new to the organization or its vendors or requires tighter tolerances or other substantial change.

If a product has multiple new or critical technologies, then a score should be developed for each of them.

This tool is also useful when choosing amongst multiple technologies that are alternatives for a single function. The scoring will help reveal information that can help your team decide which to choose.

When should the assessment be done?

This scoring system can be used before a project being approved and scheduled to help assess the product’s development challenges. It should be updated periodically as the project progresses. By tracking the technology readiness from its initial state to product release is ideally a steady increase in the DTRL score.

Who should do the scoring, and How should they do it?

It is suggested that all responsible parties score each of the critical technologies. These results then serve as a basis for conversation to iterate toward a single score for each technology evaluated. The process should be as follows:

1. Engineering develops a list of technologies that might be used in the product and that are immature, risky, or new.
2. Responsible stakeholders score each technology for which they are accountable or have knowledge. This includes not only team members, but other members in the organization and vendors who have a stake in, or knowledge about the technology.

3. During a time-boxed one-hour meeting, consensus is developed for each measure. If consensus cannot be reached in a timely (i.e., short) manner, there may be:
    - Underlying uncertainties that should become evident during the assessment
    - Inconsistent definition about the "technology" that is being evaluated
    - A need to break the "technology" into multiple sub-technologies

    The DTRL process makes these challenges evident.

4. The method gives guidance about what to focus on to refine the technology, as discussed in the section, *What to do Next*.

The Measures

There are six measures plus a Level of Confidence score that are the basis of the DTRL method. These are all on the template www.davidullman.com/DTRL/template and detailed in the sections below. It is suggested that you download the template for reference and also scoring a technology that is of interest to you.

Of equal importance to the scoring is that, for each measure, you should capture the assessment rationale, why was the score given. This becomes especially important in reaching consensus and in determining what to do next, as will be shown.

1. Technology Maturity in Your Organization

The first measure is an assessment of the organization's direct experience with the technology (Figure 2). It is based on a 9-point scale to be entered in the green box titled "Mo" (i.e., organization maturity). Mo = "5" implies that that the technology has been tried before but never matured all the way to product. In making this assessment, the rationale (in the right green box) should include proof in terms of reference to a prior project, product, or literature to support the score.

1. What is the technology maturity in the organization?	Mo=	Scoring rationale- Why did you score this measure as you did?
Common technology in group responsible for design effort. Or, New product final testing complete	9	
Common technology in other group(s) in the organization. Or, New product Beta testing complete in customer installations.	8	
Uncommon but previously used in organization in group responsible for current design effort. Or, New product Alpha testing complete and supplier capability proven.	7	
Uncommon but previously used in organization in other group(s). Or, New product tested with real materials, made with real processes, and tested in organization environment.	6	
Tried in organization but not productized. Or, Prototype tested successfully in lab for high-risk function and reliability.	5	
New to organization but with examples from similar applications. Or, Benchtop prototype passed first testing	4	
New to organization but used in non-similar applications. Or, Models of key subsystems tested on paper or computer.	3	
New application of technology Or, Principles of achieving the goal are understood.	2	
New to the world	1	

Figure 2: Organization Maturity

In applying this measure, it is often best to start at the bottom, assuming Mo = 1 and working up until you find a statement is descriptive of the status. Note that Mo = 9 addresses the group or design team directly involved, and Mo = 8 and below are focused on the organization as a whole. Also, note that each measure, except Mo = 1, has two wordings; the first is more general, and the second oriented to the level of prototype or product testing.

If you have a problem assessing a technology, consider breaking it into sub-parts or redefining what exactly is the "technology" being assessed.

The goal here is to put a single number for Mo and capture your rationale as a written statement of assumptions or specific knowledge on which your assessment is based. This will become important when trying to build consensus on your team.

The score here is the baseline DTRL value.

2. Vendor/Consultant technology maturity

An organization's knowledge about a technology can be extended through that of its vendors, consultants, or other partners. In the case that the first measure, Mo, is less than 7, there is no direct organization experience, then the capabilities of their partners can come into play, increasing the effective maturity. The assessment of this support maturity is shown in Figure 3. Note that even though only four values are shown, any number from 1 to 10 is possible.

2. What is the technology maturity of vendors or consultants? (This only applies if organization maturity is < 7)	Mv=	Scoring rationale- Why did you score this measure as you did?
Strong relationships with vendors or consultants expert in technology.	10	
Vendors or consultants with technical expertise known to organization.	6	
No vendors or consultants with knowledge known to organization but thought to exist.	4	
No vendors or consultants with knowledge known to organization. May not exist.	1	

Figure 3: Vendor/Consultant Technology Maturity

This maturity may not be as valuable as direct organization experience and thus should be discounted. For example: If you rated a technology at Mo = 5 in your organization (Question 1) and a 10 here, the updated maturity might be higher than 5, as will be discussed in *What to do Next*. Be sure to note your assumptions on the form.

3. Validation maturity

A technology is only mature if you know the important parameters that characterize it and know how to validate that those parameters can meet tests showing that they will work in your application. Figure 4 shows the area of the template used for this assessment. The goal is capturing a "V" score and rationale.

3. Do we know how we will validate it? Is there high confidence that all variables will be tested over all conceivable realistic conditions?	V=	Scoring rationale- Why did you score this measure as you did?
Fully	10	
Partially	7	
Poorly	4	

Figure 4: Validation Plan Assessment

4. Interface knowledge

No technology works by itself; it interfaces with other parts, assemblies, and systems. The knowledge of these interfaces affects the knowledge of the technology. When exploring the interfaces, think both in terms of form and function. How well do you know how the embodiment of the technology will physically fit with the other systems or people that need to interface with it? From a functional standpoint, how well do you know the flow in information, energy, materials, and control in and out of the technology's embodiment? The goal here is to capture an "I" score and rationale.

4. Are the interfaces to adjacent systems known and stable?	I=	Scoring rationale- Why did you score this measure as you did?
Fully	10	
Partially	7	
Poorly	4	

Figure 5: Interface Assessment

5. Manufacturing methods maturity

A technology is only useful if you know how to make it or get it made. This "M" measure is used to assess both the in-house and vendor manufacturing capabilities, see Figure 6. If well-known manufacturing methods are used, then this measure does not affect the maturity assessment, but if poorly known, it could reduce the overall assessment.

Note that the wording covers manufacturing regardless if it is make or buy. If the technology itself is a manufacturing method, then ignore this measure. As with all the other measures, be sure to note the assumptions and sources of information.

5. How similar are the expected manufacturing methods and tolerances on them to those currently used (hardware only, software projects = 10)?	M=	Scoring rationale- Why did you score this measure as you did?
Manufacturing and tolerances are identical to existing methods: • In-house made with stable, proven manufacturing methods • Purchased off-the-shelf from proven suppliers	10	
Manufacturing and tolerances are very similar to existing methods: • In-house needing small change to existing methods • Purchased parts require small changes to off-the-shelf parts from proven suppliers • Purchased off-the-shelf from new vendor	8	
Different from existing but no expected challenges with manufacturing process, tolerances or vendor	6	
Different from existing and challenges expected with manufacturing process, tolerances or	4	
Weak idea on how to make in volume be it in-house or by vendor	2	

Figure 6: Manufacturing Maturity

6. Specification maturity

It is important to assess how the technology is anticipated to be used, as reflected through the specifications. This assessment does not imply a specific source of the specifications; they may be imposed on the design team or developed within the team. Regardless, there is some minimal sense of specification maturity needed to ensure that a technology is suitable for the application. The design team needs to determine what this minimum level is.

6. Are the design specifications sufficiently complete, stable, and up-to-date?	S=	Scoring rationale- Why did you score this measure as you did?
Fully	10	
Partially	7	
Poorly	4	

Figure 7: Specification Assessment

7. Assessment level of confidence

Independent of the six measures above, but of equal or possibly greater importance, is the confidence (i.e., certainty) in the answers given. This is captured on a scale from "Very Low" to "Sure," as shown in Figure 7, with the result entered in "C= X". Confidence is used as an independent variable from the other six measures and is an assessment of knowledge about all of them. You could assess the confidence for each, but this is probably too detailed and not worthwhile.

The level of confidence is a measure of the level of knowledge about the technology. To help you judge this:

- Do you know the sensitivity of the technology to outside conditions?
- Do you know the failure modes and effects for the technology?
- Do you know how to control the technology throughout the life of the product?
- If asked 100 questions about the technology, would you get most of them correct?

If you answered these all in the positive, then you are an expert and should be sure of your assessment. If weak on some, then lower your level of confidence assessment.

7. Level of confidence in answers given above.	C=	What makes you certain or uncertain about this technology?
Indicate your l Level of confidence in the answers given above . 1 2 3 4 5 6 7 8 9 10 Very low, Low, So-so, Medium, High, Very High, Sure		

Figure 8: Confidence Assessment

What to do next

There are options for how to make use of this information. Option 1 is to just consider the organizational maturity with the other measures as advisory. For this option DTRL = Mo. A second option is to combine all the scores into a single value, algebraically:

$$DTRL = Mo + K_1 * Mv - K_2 * (40 - (V + I + M + S))$$

Here K_1 and K_2 are constants that can be tuned for your organization. A default value for each is .1. This equation says that DTRL = Mo with added value for vendor involvement (Mv) and a decrease in score for any weaknesses in validation, interface knowledge, manufacturing, or specifications. This will be demonstrated in the example below.

The DTRL level is then plotted versus the confidence (C) on the DTRL Summary Chart, Figure 9. An example point is shown on the chart.

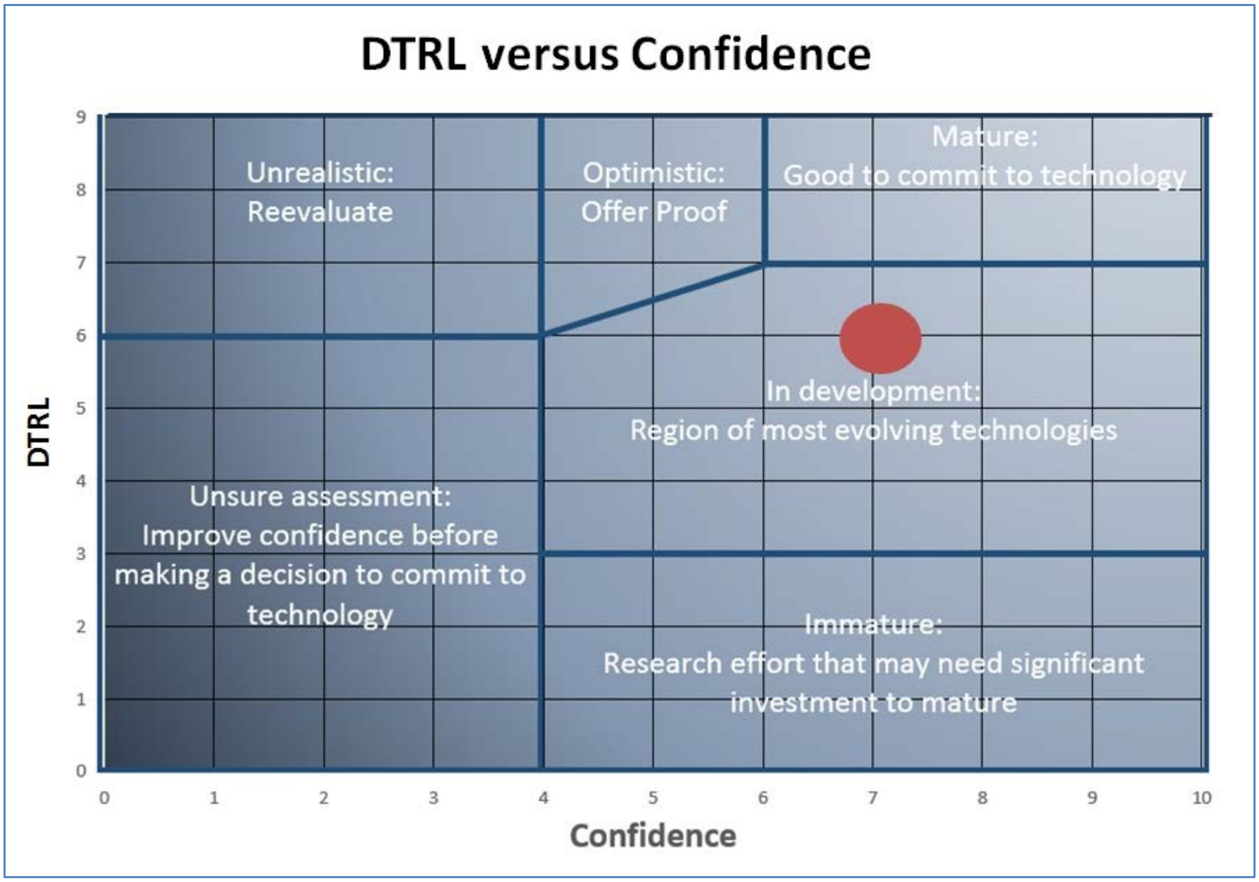

Figure 9: DTRL Summary Chart

Resulting points fall into one of six areas:

Mature: Mature technologies can be used in a new product with little or no risk. As a product matures, its point on the chart progresses toward this area. Technologies that are already used in other organization's products need not be assessed as they are well-known and mature.

In Development: Technologies in this region are well understood but are not yet mature. There is a low risk in using them. For each technology in this region, consider which measures are keeping it from being considered "mature" and work to gain knowledge and experience there.

Immature: There is high confidence that the technologies in this region are research efforts and plan accordingly. Care must be taken as work to improve the maturity could lead to higher uncertainty implying the initial assessment confidence was unrealistically high. Technologies in this region will require time, investment, and periodic reevaluation and thus are riskier than those that are in development or are mature. Other alternatives should be seriously considered.

Optimistic: The assessment of technologies in this region may be overly optimistic, given the level of certainty. It is suggested that others evaluate the technology, and the results of their assessments factored in.

Unsure: Technologies here can be used but with some risk. As experience is gained and the assessment confidence is improved, it may become evident that they are more or less mature than originally thought. This can be visualized as the points in this region moving to the right as more is learned. As they move right, they may move into an area of Development, or they be increasingly seen as Immature. Clearly, technologies in this region are risky and those with less maturity, the riskiest.

Unrealistic: A technology is this region implies that the evaluator sees it as mature but is not very confident in this assessment. This is equivalent to the assessor saying that he is not sure of what he is sure is a good technology to use. It is suggested that others reevaluate this technology.

An Example

Bob and Belinda are members of a design team at Nutran Industries, a manufacturer of consumer products. On their new Poseidon project, they are considering integrating a radio frequency (RF) transmitter in the system (Figure 9). Bob is the Product Owner who has been with the company for seven years and led many products to release. Belinda is a recent graduate electrical engineer who has taken recent courses in RF applications.

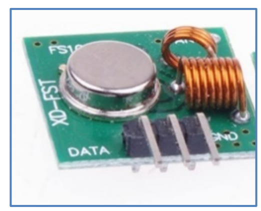

Figure 10: RF transmitter

They independently assess the RF transmitter to find its DTRL. The comparison of their results is shown in Figure 11. The comments for each measure explain their rationale for the assessments. Note that this comparison fosters conversations about validity testing and interfaces, areas they disagree on.

	Bob	Belinda	Comments
Maturity in Organization, Mo =	5	7	Bob knows the organization's history with RF, but Belinda brings new knowledge and has spoken with some suppliers who have a proven RF track record.
Vendor Maturity, Mv =	8		Bob also knows a consultant who expert in RF applications.
Validity, V =	3	6	Belinda thinks the tests are better defined than does Bob. This may be consistent with the interface evaluation.
Interfaces, I =	5	8	There is significant disagreement. An opportunity to discuss and ensure the interfaces are consistently understood.
Mfg, M =	9	9	Agreement
Specs S =	7	8	Essentially in agreement.
Confidence, C =	7	4	

Figure 11: Assessment Example Results

The results interpreted in two ways are shown in Figure 13: the light red shows their results with DTRL = Mo and the dark red using the formula introduced earlier.

Regardless of which option is considered, Belinda's maturity assessment and her lack of confidence results in her point landing on the optimistic-unrealistic border, not surprising for a recent graduate.

Bob's raw assessment puts DTRL = 5. His inclusion of the vendor raises this to DTRL = 5.8 = (.5 + .1 * 8), but the other factors lowers this to DTRL = 4.2 = (.5 + .1 * 8 - .1 * (40 – (3 + 5 + 9 + 7))) as shown by the darker point. In either case Bob sees the RF transmitter's use in the product as firmly in the development area.

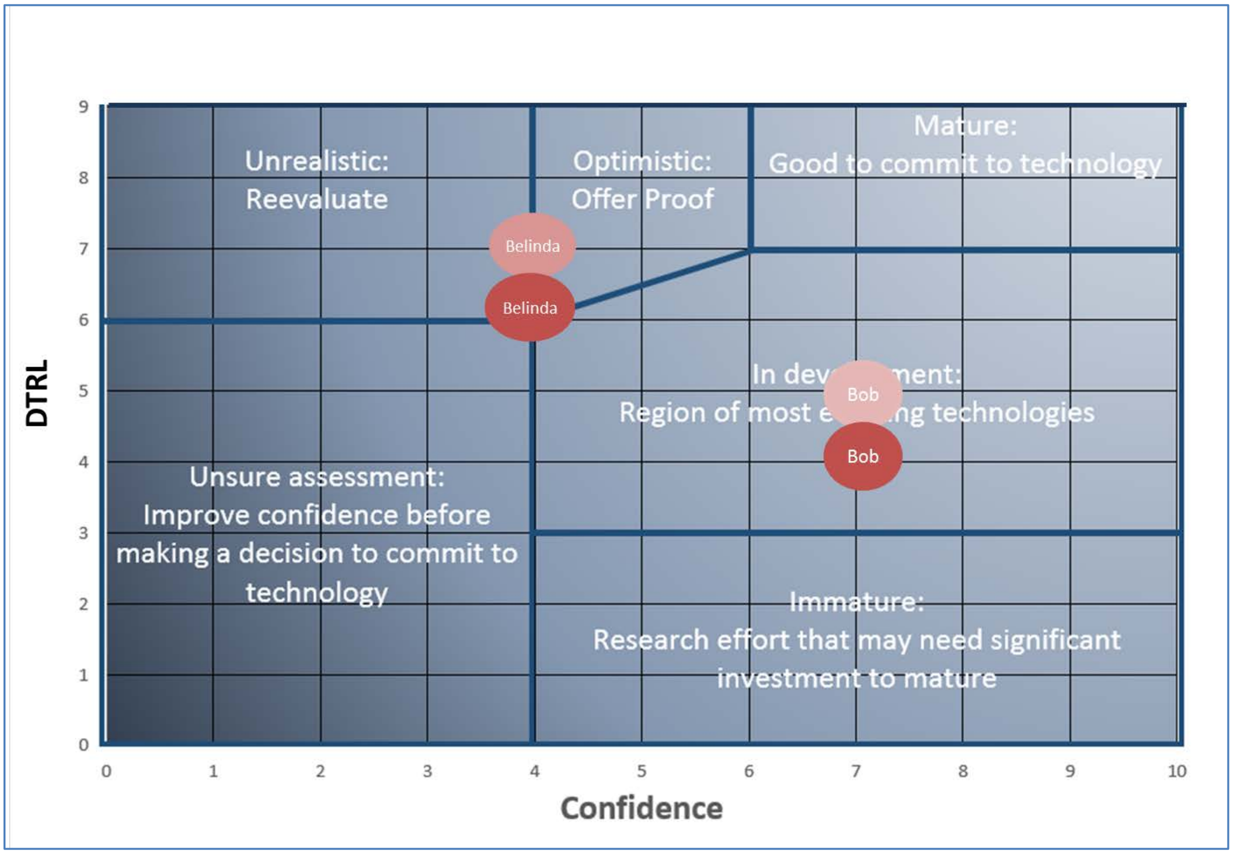

Figure 12: Example DTRL

The value of this exercise to Bob and Belinda's team is summed up in the following section.

Conclusion

The completion of the Design Technology Readiness Level form has given Bob and Belinda's team a window into the maturity of the RF transmitter in their new product. Further, this window can be opened to others outside the team, especially those teams responsible for systems that interface with the RF transmitter. These results also make clear the areas needing effort, validity testing, and interfaces. Possibly the addition of a test engineer to the evaluation will be of benefit to help identify what is needed to test the RF transmitter as the product evolves.

These results have exposed Belinda's knowledge about RF transmitters, possibly not well understood prior to this evaluation. Her youthful optimism may also breathe some fresh thinking into all areas of the RF transmitter's development.

Based on what has been uncovered, the risks in using the RF transmitter in the product are not high. The specifications are fairly well developed, and manufacturing is not an issue.

While this exercise may not have developed any new analytical results, it has made very important aspects of the RF transmitter's use evident. If the team had been exploring another alternative technology for use in the product, an option B, the assessment of both the technologies would provide a clear basis to compare and contrast them.

The NASA developed TRL nine-level scale has become useful jargon, and it is common to hear "this technology is at TRL4" or the like. Since there are six dimensions to the DTRL assessment, there is more information content, and so Bob, the product owner, might say, "The RF transmitter is at DTRL4 with level 6 confidence and concern about the interfaces and validation." Not as brief, but certainly more information-rich.

Sidebar
David G. Ullman is a retired design professor and ASME Life Fellow. His text, "The Mechanical Design Process," 6th edition, is a compendium of best practices used at many universities to help students learn how to get from need to product. It has been in print since 1992. His latest material is on "Scrum for hardware and System Design." See www.mechdesignprocess.com for details. Feel free to share comments or questions with him at ullman@davidullman.com