Technology Readiness Levels (TRLs) are a numerical classification on the status of the development of a technology. TRLs provide a common language whereby the status of a technology can be described without the need to have an understanding of the technology itself.

1. Steps to Track TRLs within DMTC projects

    i. Prepare a Technology Readiness Assessment (see following Technology Readiness Levels Guide).
    ii. Define the current TRL levels of the technology and the target TRL levels at project completion (see following Technology Readiness Levels Guide).
    iii. Review status and progress of TRL advancement in project reviews.
    iv. Ensure that the TRLs fit with the technology trajectories described in the Impact Tool.
    v. Document TRL status in project completion statement.

2. Reference documents

    Project initiation procedure

    Project review procedure

    Project closure procedure

Technology Readiness Levels

Technology Readiness Levels (TRLs) are used as standardised numerical indicators of the level of maturity of a technology. The standard TRL definitions are given in Table 1. The descriptions given in the following table are generic and should be used to guide the compilation of a technical description of each TRL for every technology being developed. Additional terms and definitions are given in the example case studies provided at the end of this Guideline.

Table 1: TRL definitions

Phase	TRL	Description	Key indicators	Examples- see case studies at end of document
Research phase	1 Basic principles observed and reported	Lowest level of technical readiness. Examples might include paper studies of technology's basic principles. Study of published research that identifies the principles underlying the technology. References to who, where, when.	Basic identification of opportunity.	**Vehicle bumper**: Study of possible materials to reduce weight for bumpers. **Helmet**: Study of ballistic performance of materials. **Robotic welding**: Study of state of autonomous welding welding processes. **New steels for shipbuilding:** Literature review of properties of new high strength ship steels. **Titanium machining optimisation**: Understanding of metal removal from prior work.
Research phase	2 Technology concept and / or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytical studies. Desk top study.	Concept formulation. Technology review leading to understand market position of technology	**Vehicle bumper**: Established concept for bumper design. **Helmet**: Established concept for manufacturing process for helmet shell. **Robotic welding**: Established concept for autonomous welding system incorporating automated offline programming, identifying technology gaps. **New steels for shipbuilding**: Map ADF potential future requirements and assess candidate materials. **Titanium machining optimisation**: Identification of the key issues affecting titanium machining from literature.

Phase	TRL	Description	Key indicators	Examples- see case studies at end of document
Research phase	3 Analytical and experimental critical function and / or characteristic proof of concept	R&D underway. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative system.	Research results support concept.	**Vehicle bumper**: Bumper CAD model tested with FEA **Helmet**: Computer simulation modelling of forming process to produce helmet shell. **Robotic welding**: Development of algorithms for robots to map three dimensional geometries. **New steels for shipbuilding**: Model and identify potential compositional ranges for candidate steel. **Titanium machining optimisation**: Laboratory testing of cooling systems, new tooling and vibration monitoring systems.
Development phase	4 Component validation in a laboratory environment	Successful integration of basic components. Core technical risk of the system is reduced. System concepts supported by laboratory trials. Examples include integration of “ad hoc” hardware in the laboratory.	Industry engagement in project. Value proposition stated.	**Vehicle bumper**: CAD model validated with materials testing in laboratory. **Helmet**: Laboratory testing of UHMWPD formed in by double diaphragm deep drawing. **Robotic welding**: Laboratory demonstration of robot mapping dimensional geometries and identifying joints. **New steels for shipbuilding**: Produce candidate steel in laboratory volumes for testing. **Titanium machining optimisation**: Identify improvement efficiencies associated with new practices in a laboratory setting.

Phase	TRL	Description	Key indicators	Examples- see case studies at end of document
Development phase	5 Component validation in a relevant environment	Resolution for the operation and implementation of the technology increases significantly. The basic technology components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Results from testing a laboratory system are integrated with other supporting elements in a simulated operational environment.	Industry provides specifications and/or materials. Competitive advantages of technology specified.	**Vehicle bumper**: Weight, mounting and corrosion control consideration for vehicle bumper are integrated into design. **Helmet**: Helmet shell formed that meets specification. **Robotic welding**: Demonstration of autonomous robotic mapping of geometries then welding of joints. **New steels for shipbuilding**: New steel alloy produced in small quantifies that meets design specifications and weldability requirements. **Titanium machining optimisation**: Development prototype system(s) for operation (e.g. laser assisted machining cell).
Development phase	6 System / sub-system or prototype demonstration in a relevant environment	Representative model or prototype system which is well beyond TRL 5 is tested in a relevant environment. Represents a major step up in a technologies demonstrated readiness. Examples include testing a prototype in a representative environment for end use. Results from laboratory testing of prototype system that is near the desired configuration in terms such as performance, weight and volume.	Prototype meets industry expectations. Prototype meets external stakeholder requirements.	**Vehicle bumper**: Prototype bumper manufactured and tested. **Helmet**: Helmet shell is incorporated into a prototype helmet (mounting, painting, harness). **Robotic welding**: Autonomous robotic welding cell welds joints with geometries representative of final application. **New steels for shipbuilding**: Scale up demonstrated for steel production. **Titanium machining optimisation**: Demonstrate technology at industry scale on representative geometries.

Phase	TRL	Description	Key indicators	Examples- see case studies at end of document
Industry utilisation phase	7 System prototype demonstration in a simulated operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space). Results from testing a prototype system in an operational environment.	Industry undertakes testing. Customer undertakes testing.	**Vehicle bumper**: Bumper tested on vehicle. **Helmet**: Prototype helmet is tested against full end user specifications. **Robotic welding**: Autonomous robotic welding cell at end user site demonstrates new technology. **New steels for shipbuilding**: New steel alloy meets fully specifications for ship building. **Titanium machining optimisation**: Trial technology package at industry sites on real components.
Industry utilisation phase	8 System qualified through test and demonstration in a simulated operational environment	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications. Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements	Certification by external party. Customer acceptance. R&D ceased.	**Vehicle bumper**: Bumper certified/qualified for production. **Helmet**: Helmet tested by army and meets all requirements for adoption. **Robotic welding**: Autonomous robotic welding defined as standard operating procedure for specific welding applications. **New steels for shipbuilding**: Certification of ship building steel by relevant agency. **Titanium machining optimisation**: Certification of new process as standard procedure.

Phase	TRL	Description	Key indicators	Examples- see case studies at end of document
Industry utilisation phase	9 System qualified through mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	Industry controls technology. Customer controls technology. Product for sale. Practice routinely used in production.	**Vehicle bumper**: Bumper a component on defence vehicle. **Helmet**: Helmets used by defence. **Robotic welding**: Autonomous robotic welding routinely used with production of Bushmaster vehicles. **New steels for shipbuilding**: Ship constructed out of new steel. **Titanium machining optimisation**: Adoption of new process for manufactured components.

Target Performance Measures

The purpose of Target performance measures (TPMs) is to guide the technology development and help assess the TRL at each development milestone. TPMs for each technology must be established and documented. The following criteria must be taken into account when establishing TPMs.

- Establish the context of use of the technology
- Establish technology boundaries
- Define testing requirements
- Define test report requirements
- Define TRL requirements

Technology Readiness Assessment

A Technology Readiness Assessment (TRA) must be conducted at each development milestone to verify the TRL. The TRA must include the Project Leader, Subject Matter Expert in the technology, Subject Matter Expertise in the area of application of the technology and at least one independent person with knowledge of the technology or application. The outcomes of the TRA must be documented. The following criteria must be taken into account when conducting a TRA.

- Review actual performance against the target performance measures
- Assess the deltas using engineering judgement
- Decide if technology maturity has been demonstrated
- Make recommendations for the next phase of development

Example 1:

Technology Context:

Hydrogen Fuel Cell Energy Source for top-up charging of proton flow batteries of the type carried by the Storm Troopers of the Empire.

Technology Boundaries:

System shall have physically mount inside the Storm Trooper Armoured Exoskeleton.

System shall have a functional and physical with the Jedi X2 Power Manager.

Target Performance Measures

TPM No	Performance Measure	Target	Minimum	Comment
1	Wattage	100W	50W	Bases on as designed dimensions.
2	Voltage	20V	10V	Operating range of Jedi X2 Power Manager
3	Cartridge Capacity	200 W-h	200 W-h	Constrained by cartridge manufacturer
4	Operating Conditions	Maintain power over a temp range of -100 to 100 ^{0}C	Maintain power over a temp range of -200 to 200 ^{0}C	Based on Tatooine invasion scenario

TPM No	Performance Measure	Target	Minimum	Comment
5	Noise level	3 dB or less at 1 metres	3 dB or less at 5 metres	Not even a dog can hear it
6	System Energy Density	2200 W-h/kg (tbc)	2000 W-h/kg (tbc)	To recharge battery for rail gun
7	Life-cycle	1500 cycles	2500 cycles	Number of charge cycles

TRL Requirements

TRL	Description	TPM	Documentation
3	Proof of concept system design completed	TPMs for subsequent milestones agreed	Functional specification & design drawings
4	Components tested on a laboratory bench (MIL-STD-810)	TPM 1 -2 verified	Component validation report
5	System tested on a laboratory bench (MIL-STD-810)	TPM 1-5 verified	System validation report
6	Optimised system tested on a laboratory bench (MIL-STD-810)	TPM 1-6 verified TPM 7 estimated	System validation report

Example Case Studies

Vehicle Bumper	
Technology: A new light weight bumper bar for a new defence land vehicle (e.g. Hawkei).	
TRL 1	Study of possible materials to reduce weight for bumpers
TRL 2	Established concept for bumper design
TRL 3	Bumper CAD model tested with FEA
TRL 4	CAD model validated with materials testing in laboratory
TRL 5	Weight, mounting and corrosion control consideration for vehicle bumper are integrated into design
TRL6	Prototype bumper manufactured and tested
TRL 7	Bumper tested on vehicle
TRL 8	Bumper certified/qualified for production
TRL 9	Bumper a component on defence vehicle

Helmet	
Technology: A helmet manufactured from UHMWPE using the double diaphragm deep drawing process.	
TRL 1	Study of ballistic performance of materials
TRL 2	Established concept for manufacturing process for helmet shell
TRL 3	Computer simulation modelling of forming process to produce helmet shell
TRL 4	Laboratory testing of UHMWPD formed in by double diaphragm deep drawing
TRL 5	Helmet shell formed that meets specification
TRL6	Helmet shell is incorporated into a prototype helmet (mounting, painting, harness)
TRL 7	Prototype helmet is tested against full end user specifications
TRL 8	Helmet tested by army and meets all requirements for adoption
TRL 9	Helmets used by defence

Robotic welding cell	
Technology: A robotic welding cell that utilises automated offline programming to determine welding paths and then applied to the Bushmaster welding operations at Thales	
TRL 1	Study of state of autonomous welding welding processes
TRL 2	Established concept for autonomous welding system incorporating automated offline programming, identifying technology gaps
TRL 3	Development of algorithms for robots to map three dimensional geometries
TRL 4	Laboratory demonstration of robot mapping dimensional geometries and identifying joints
TRL 5	Demonstration of autonomous robotic mapping of geometries then welding of joints
TRL6	Autonomous robotic welding cell welds joints with geometries representative of final application
TRL 7	Autonomous robotic welding cell at end user site demonstrates new technology
TRL 8	Autonomous robotic welding defined as standard operating procedure for specific welding applications
TRL 9	Autonomous robotic welding routinely used with production of Bushmaster vehicles

New steels for shipbuilding	
Technology: Development of new grades of HSLA65 steel with suitable properties for shipbuilding , including demonstration of weldability.	
TRL 1	Literature review of properties of new high strength ship steels
TRL 2	Map ADF potential future requirements and assess candidate materials
TRL 3	Model and identify potential compositional ranges for candidate steel
TRL 4	Produce candidate steel in laboratory volumes for testing
TRL 5	New steel alloy produced in small quantifies that meets design specifications and weldability requirements
TRL6	Scale up demonstrated for steel production
TRL 7	New steel alloy meets fully specifications for ship building
TRL 8	Certification of ship building steel by relevant agency
TRL 9	Ship constructed out of new steel

Titanium machining optimisation	
Technology: Operational practices that increase the efficiency of titanium machining operations in the aerospace sector	
TRL 1	Understanding of metal removal from prior work.
TRL 2	Identify proposed technologies to be developed/tested/transferred
TRL 3	Laboratory testing of cooling systems, new tooling and vibration monitoring systems
TRL 4	Identify improvement efficiencies associated with new practices in a laboratory setting
TRL 5	Development prototype system(s) for operation (e.g. laser assisted machining cell).
TRL6	Demonstrate technology at industry scale on representative geometries
TRL 7	Trial technology package at industry sites on real components
TRL 8	Certification of new process as standard procedure
TRL 9	Adoption of new process for manufactured components