Abstract—We propose a novel methodology to overcome the outstanding challenges in effectively assessing technology maturity to final real-world applications. The Engineering Severity Level (ESL) is a conceptual tool that provides a simple, standardised and quantitative method for assessing technology suitability to real-world environments. It is a standalone tool offering advantages in generating an evidence base for accurate technology maturity assessment and early identification of developmental roadblocks. Moreover, the tool can be applied as a universal basis to enhance Technical Readiness Level (TRL) classification and provide further context and quantitative analysis. The benefits are exemplified in the assessment of quantum technologies for Position, Navigation and Timing (PNT) requirements in Defence applications.

Index Terms—technology maturity level, prototype development, quantum technology, systems engineering, technology assessment, technology readiness level, technology development, technology maturity, TRL.

I. INTRODUCTION

Developing new technologies is crucial for industry sectors, government bodies, and financial investors to maintain commercial leadership and national capabilities. Despite its importance, identifying specific areas for technology research and development to invest in can be challenging, and these decisions can significantly impact investors’ confidence in novel technologies and, ultimately, product viability. To make informed decisions, technology developers and investors require an accurate assessment of a technology’s maturity in both performance and form-factor relative to its intended real-world application. Nonetheless, assessing technology maturity in both areas has been a challenge and an active area of research since the 1950s.

The Technology Readiness Level (TRL) classification system [1] has been widely adopted ¹, however, it has been criticised for being too subjective and lacking functionality relative to changing expectations over time. This has resulted in programme delivery shortfalls and issues that highlight the need for a maturity tool that provides clear evidence for classifying technology maturity [2-6].


This paper presents the Engineering Severity Level (ESL) a new tool designed to overcome known challenges in developing fit-for-purpose technology. The ESL tool complements and enhances the TRL definition, creating a standardised and quantitative method for accurately assigning a maturity level. This article serves as a guide for technology developers in government, academia, and industry sectors to adopt the ESL tool.

II. BACKGROUND

The TRL classification system is a widely adopted method for assessing technology readiness and promoting testing and verification. However, it has received criticism for not being fit for purpose. Despite the creation of supporting software and calculators [7-8], a classification framework [9] and a readiness assessment guide [10], challenges persist. These challenges can be summarized into four dominant contributing factors:

• The TRL classification measures technology readiness based on a generalized requirement to operate, but it does not consider functional aspects such as the technology’s ability to operate within a system or produce a real-world operational outcome. Additionally, it treats the technology as a singular entity, rather than considering its holistic capabilities [11 – 15].
• Aspects of the TRL classification are subjective, and understanding of the world and the inherent acceptance of risks vary vastly from person to person. For example, there is no standardised measure of the operational physical environment from TRL 5 to 7 [16 – 17].
• Technology readiness does not necessarily reflect technology maturity timelines and does not capture development lifecycles required to transition up the scale. The scale is a rigid binary metric, lacking in functionality relative to changing expectations as time passes [11, 14 18 –21].
• TRL classification supports identifying potential risk areas, but it does not provide a metric to assess the associated risk or the degree of difficulty in transitioning from one readiness level to another [6, 22-24].

The subjectivity and limited functionality of the TRL combined with overconfidence [15-17] in the ability to deliver technology, have been identified as major factors contributing to failed technology insertion [28-32].

Numerous alternative methods have been proposed to overcome these challenges, with one review identifying 409 relevant papers on the subject [33]. These ideologies range from simple adaptations to the current TRL metric [33-34]

Susannah Jones, Defence Science and Technology Laboratory.
or linking TRL to other standardised architecture frameworks [14]; to a plethora of readiness levels that incorporate TRL, each offering an improved ability to accurately assess technology maturity. A non-exhaustive summary of relevant readiness levels and how they interconnect is presented in Fig. 1.

![Fig. 1: Summary of readiness level classification approaches and how they interlink in support of the development of technology and assessing maturity.](image)

The matrices, indices, and assessments presented in Fig. 1 vary in complexity and often require a Subject Matter Expert (SME) to interpret and assess the technology’s maturity in relation to the final operational requirement. One such example is the Cornford and Sarsfield Developmental Maturity Index (DMI) [36], which was created as a replacement for TRL and uses a set of subjective measurements to link the system-of-systems approach. The DMI repeatedly assesses technology Key Engineering Performance Parameters (KEPPs) throughout the development cycle, addressing the issue of technology maturity assessment by including developmental targets. However, each component’s targets are unique and require an SME to assign and negotiate the acceptance development cycle. A significant advancement in technology development assessment is the ability to mathematically quantify a technology’s maturity in terms of readiness of internal system integration between components, provided by Sauser’s System Readiness Level (SRL) [34]. Since the creation of the SRL, further developments have been made linking technology maturity with system-of-systems and systems engineering architectures [42 - 44].

Improved computer modelling and 'Digital Twins’ can provide quantifiable evidence of technology maturity, but their cost increases with the reliability and complexity of the models. As a result, their use in technology development can be limited. Therefore, there is a need for a standardised, simplistic tool in industry and academia to objectively define technology maturity and quantify its overall capability against real-world operational requirements.

This paper investigates the creation of a tool to assess technology development maturity based on final operational requirements, providing an evidence base for maturity classification. The tool consists of two data capture tools: the Engineering Severity Level (ESL) matrix and the Size, Weight, and Power (SWaP) matrix, as well as the Mapping Associated Parameters (MAP) methodology to correlate the data sets against a specific application. The combination of these tools generates a quantitative evidence base to assess technology development stages and identify critical research and investment areas. The ESL tool also redefines the level descriptions of the current TRL classification, creating the 'TRL+' classification, a standardised and quantitative metric for technology maturity assessment.

The following sections provide a complete description of the ESL and SWaP matrices for technology and its intended platform. In this context, ‘platform’ refers to the host entity into which a technology is integrated. The Mapping Associated Parameters (MAP) process is introduced to quantify the technology’s goodness-of-fit to the platform and provide evidence for investment in improving the fit. Additionally, the paper discusses how these tools can complement and enhance the TRL tool. In Section V, an example is presented of using these tools in the emerging field of quantum technology and their application in demanding defence and security platforms.

### III. Methodology

In this section, the paper describes how the parameters and their ranges are defined within the Engineering Severity Level (ESL) matrix (Part A). Two versions of the ESL are created: the Platform Technology Requirements Matrix, which defines the environmental conditions that the technology must operate within (Part B), and the Technology Capability ESL Matrix, which identifies the technology’s environmental robustness at a specific stage in its development (Part C).

#### A. Engineering Severity Level dataset matrix

A technology or system must operate within a technical performance envelope in a platform operating in a real-world environment. The ESL matrix (Fig. 2) captures the range of platform environments by drawing together disparate data sources and common platform environment parameters in a single dataset. The severity of each parameter is indicated along the matrix column’s vertical axis, ranging from a benign laboratory environment (ESL = 0) to the most extreme platform environments that technology must withstand (ESL = ∀).

The ESL matrix is designed to represent any environmental parameter, with user-definable ranges and increments to capture the necessary granularity of operational environments. We evaluated military platform environmental param-
eters and found that physical conditions, such as temperature, pressure, acoustic noise, vibration, and electromagnetic field characteristics, are common across all platforms. The investigation also found that environmental parameter severity varies by platform type, with large ships having relatively benign conditions comparative to tanks or rockets. In a real-world scenario, a technology must operate in a complex combination of environmental events over timescales relating to platform operation and service lifetime. The values within the ESL matrix represent an approximated single independent event at a specific location within a platform but can be applied to real-world scenarios as a snapshot of common platform environmental parameters. Fig. 3 shows an example of a real-world ESL matrix created from the investigation.

Fig. 3: Example of real-world ESL matrix, populated with representative values for a range of sea, land and air military platforms.

**B. Platform requirements ESL matrix**

The purpose of technology is to provide continuous performance or survive extreme environmental events, resuming operation when conditions return to normal. The ESL platform matrix is used to distinguish between survivable and operational parameters by colour-coding each cell, with green representing operational and yellow denoting survivable. A weighted score is assigned to each modality identified by each colour to reflect its relative importance, and these scores are used in a comparative best-fit quantitative analysis with technology capability to obtain a ‘maturity percentage’ value. In the example shown in Fig. 4, the operate function has a greater weighted value (two) than the survive requirement function (one). The platform operate value is calculated by summing the values under the solid black line, while the platform survive value is calculated by summing the values under the broken black line and above the solid black line. In the example presented in Figure 4, these values are 30 and 8, respectively. These values are used in the MAP-ESL process described in Part D of this paper.

Fig. 4: Platform ESL requirement matrix with platform profiles and profile values, which are used in the MAP process in part D. Where green denotes operate with a technical performance and yellow survive. The solid and broken lines in bold are the platform’s operate and survive profiles, respectively.

**C. Technology Capability ESL matrix**

A separate ESL matrix is used to capture the technology’s ability to function in various environments, using the same method as the platform requirement matrix. The matrix identifies the technology’s operate (green) with technical performance and survive (yellow) with degraded or no technical performance capabilities. Numerical values are assigned to each based on the weighting used within the platform requirement ESL matrix. The ESL matrix can also capture additional information, such as conditions where the technology is unproven (grey) or fundamentally unable to survive (red). However, this information is not given a weighted score. Fig. 5 shows the technology capability ESL matrix, with numerical values used in the MAP process described in Section D.

Fig. 5: Technology capability ESL Matrix. Numerical values are used in the MAP process described in section D. Here, red indicates the technology is unable to operate, and grey represents that the performance is unknown.

**D. Mapping Associated Parameters (MAP)**

The MAP numerical analysis provides a way to quickly identify discrepancies or mismatches between technology
parameters and platform requirements, enabling targeting of technological development, or trading non-key performance requirements for time or cost parameters. The analysis derives a coarse percentage fit of the technology’s environmental functional capability for the platform in question, with details indicating opportunities for compromise and development. Fig. 6 shows an example in which the solid and dashed lines from the platform requirements ESL (Fig. 4) are overlaid on the technology capability ESL (Fig. 5). The total number of green cell values under the platform operate profile (solid black line) is summed and compared with the platform operate profile value to yield a percentage fit. In the example in Fig. 5, the total green cell value is 16, and the platform operate profile value is 30 (Fig. 5). Therefore, the percentage fit of technology operate capability to platform operate requirement is (16/30) x 100 = 53%. Similarly, the suitability percentage of the technology to meet the platform survive requirement is evaluated by summing the total values in each yellow cell that lies below the platform survive (a value of two in the example shown in Fig. 6) and above the platform operate profiles (a value of eight in the example shown in Fig. 6). Comparison of these values is made to calculate the coarse percentage fit of technology survive capabilities to platform operate requirement, in this example, 25%.

E. Size, Weight and Power ESL process

SWaP constraints are a crucial factor in determining a technology’s ability to provide a functional role on a platform. The common SWaP constraints for integrated technology are represented as three variables in a single two-dimensional SWaP matrix dataset, as shown in Fig. 7. Each cell within the matrix represents the SWaP available for a technology, with the most severe SWaP constraints in the top left matrix cell and the least severe in the bottom right matrix cell. The value of each cell is customisable for the user’s requirement and can be adapted for real-world scenarios, as demonstrated in Fig. 8.

In the MAP process, each SWaP cell is colour-coded and assigned a weighted score to represent the current (orange, with a value of four in the example shown in Fig. 9) or potential (purple, with a value of two) aptitude of the platform SWaP requirements. In this context, ‘potential’ refers to the ability to modify a platform to facilitate a larger technology SWaP. A solid black line is drawn around the perimeter of the cells that span the current SWaP requirement, while a dashed black line is drawn around the perimeter of the cells that span the potential platform SWaP requirement.

An example of a technology’s current SWaP is presented in Fig. 10, where each SWaP attribute is assigned a numerical value identical to those used within the platform SWaP requirement matrix, allowing for a direct comparison.

The MAP process involves overlaying the platform SWaP attribute profiles onto the technology SWaP capability matrix, as presented in Fig. 11. This enables the evaluation
Fig. 9: Shows the platform SWaP requirement matrix, with platform profiles where orange indicates current requirement and purple potential requirement (meaning the platform would require modification) and the solid and dashed outlined boxes are the current and potential SWaP requirements.

Fig. 10: Shows the technology SWaP capability matrix.

Fig. 11: Shows the results of the MAP-SWaP process, where the platform SWaP requirement profiles (solid and dashed) have been overlaid onto the technology SWaP capability matrix.

In the example presented in Fig. 11, the technology meets 100% of the current platform SWaP requirement but 0% of the future requirement. Overall, the MAP-SWaP process provides a systematic approach to evaluating a technology’s SWaP capabilities to meet the platform’s SWaP requirements, allowing for the identification of areas where the technology’s SWaP capability exceeds or falls short of the platform’s SWaP requirements, thereby providing opportunities for compromise and development.

F. TRL Redefined

The ESL analysis method provides a simple, accessible language for targeting areas of interest to technology integrators, developers, and investors. It also provides an auditable evidence trail for technology development and acquisition and can highlight contextual technology limits concerning real-world applications.

Whilst the ESL tool can be used as a standalone tool, it is proposed that the tool be applied as a standardised, universal quantitative basis within the TRL classification scheme to provide further context and evidence-based definitions, as shown in Fig. 12.

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TRL+ Classification

<table>
<thead>
<tr>
<th>TRL+</th>
<th>Description</th>
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<tbody>
<tr>
<td>TRL+ 9</td>
<td>Actual technology qualified through successful mission operations</td>
</tr>
<tr>
<td>TRL+ 8</td>
<td>Technology capability meets 100% of ESL &amp; 100% of SWaP requirements in operational environment</td>
</tr>
<tr>
<td>TRL+ 7</td>
<td>Technology prototype capability meets 75% of ESL &amp; 75% of SWaP requirements in operational environment</td>
</tr>
<tr>
<td>TRL+ 6</td>
<td>Technology prototype capability meets 100% of ESL &amp; 50% SWaP requirements in controlled environment</td>
</tr>
<tr>
<td>TRL+ 5</td>
<td>Technology prototype capability meets 50% of ESL &amp; 50% of SWaP requirements in controlled environment</td>
</tr>
<tr>
<td>TRL+ 4</td>
<td>Novel prototype capability meets each parameter ESL 0 in a controlled environment</td>
</tr>
<tr>
<td>TRL+ 3</td>
<td>Analytical and experimental critical function and/or characteristic proof of concept</td>
</tr>
<tr>
<td>TRL+ 2</td>
<td>Technology concept and/or application formula</td>
</tr>
<tr>
<td>TRL+ 1</td>
<td>Basic principles observed and reported</td>
</tr>
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</table>

The TRL+ESL (or simply TRL+) classification is based on the MOD TRL classification [45] but applies the ESL and SWaP matrices to redefine the definitions of levels 4 to 8. In the TRL definition, TRL 4 represents basic validation of a technology in a laboratory environment without size, weight, and/or power constraints. This is equivalent to the ESL 0 for each environmental parameter. For example, the temperature of a laboratory is 20°C, and pressure is standard atmospheric pressure 101kPa, as shown in the example ESL in Fig. 3. Hence, a novel technology is TRL+ 4 when demonstrating a set performance capability within a benign laboratory environment with environmental parameters defined by ESL 0. At present, the environment and SWaP of TRL 5, 6, 7 and 8 are not quantitatively defined. However, applying the ESL and SWaP matrices can lead to a quantitative and standardised metric within the TRL classification definition as follows:

- **TRL+ 5**: when demonstrating a set performance capability within a controlled environment that meets a minimum of 50% of an ESL platform environment requirement and a form factor and power capability matching at least 50% of the SWaP requirement.
- **TRL+ 6**: when demonstrating a set performance capability within a controlled environment that meets a...
minimum of 100% of an ESL platform environment requirement and with a form factor and power capability meeting at least 50% of the SWaP requirement.

- TRL+ 7: when demonstrating a set performance capability within the intended operational environment that meets a minimum of 75% of an ESL platform environment requirement with a form factor and power capability meeting at least 75% of the SWaP requirement.

- TRL+ 8: when demonstrating a set performance capability within the intended operational environment that meets 100% of an ESL platform environment requirement with a form factor and power capability meeting at least 75% of the SWaP requirement.

The ESL architect sets the definition of a controlled environment, which can include laboratory simulated testing, testing a prototype on a platform that is not the intended final platform, and/or on the intended platform when not carrying out full operational manoeuvres.

The ESL tool is not intended to be used as a standalone systems engineering tool but as a standardised methodology for quantitatively assessing and defining technology maturity classification and identifying areas of research and development within the development process. However, applying the ESL tool to redefine the definitions within the TRL classification allows the TRL+ to be used alongside many of the system engineering tools and classifications mentioned in Fig. 1.

IV. INVESTIGATION

Quantum 2.0 technology [46] has vast potential applications with significant impact on humanity, similar to the transistor. However, the underlying science is complex, and developing low TRL quantum technology is expensive and requires targeted investment. Without evidence-based development, the resulting technology may not be fit for purpose.

The UK defence and security sector requires highly accurate and resilient Position, Navigation, and Timing (PNT). When Global Navigation Satellite Systems (GNSS) are unavailable, an Inertial Navigation System’s (INS) error accumulates, compromising mission success. The Defence science and technology laboratory’s (Dstl) Quantum Sensing Project aims to augment current INS with next-generation quantum sensing capability to achieve a robust and enduring PNT solution. This section explains how the ESL methodology was trialled during a quantum-augmented PNT (Q-PNT) funding call from the Defence And Security Accelerator (DASA), a Ministry of Defence innovation funding body.

A. Q-PNT First Adopters

The Quantum Sensing Project identified ten first adopter platforms for an investigation into Quantum-Augmented Position, Navigation, and Timing (Q-PNT). These platforms represent various domains and operational complexities, with corresponding environmental requirements captured in ESLs. The platforms cannot be identified due to their classified nature, but two platforms A and B were chosen for proof of concept demonstration, as shown in Fig. 13 and 14. For both platforms, the “operate” attribute requires technology to meet set performance 90% of the time, and the “survive” attribute requires it to operate immediately within the “operate” environmental parameter range.

B. Q-PNT Investigation

The Quantum Sensing DASA research call "Reducing Reliance on Global Navigation Satellite Systems with Q-PNT," released on November 2, 2020. The aim of the call was to reduce reliance on global navigation satellite systems by focusing on sensing technology between TRL 4 to 6 [49], such as atomic clocks, quantum-enabled accelerometers, gyroscopes, gravity, and magnetic field sensors. Research proposals were required to provide evidence of advanced sensing performance or enhanced environmental operational capability within a five-year time frame through six-month feasibility studies. Suppliers were required to use the ESL and SWaP matrices to show the potential progression of the device’s physics package and driving devices from the current technical prototype to the future operational environmental capability.

Suppliers used the ESL matrix (Fig. 3) with colour coding (Fig. 15) and the SWaP matrix (Fig. 8) with colour coding (Fig. 16) to demonstrate the progression of the device’s physics package and driving devices include all system components other than power generation, such as lasers, optics, acoustic, optical modulators, amplifiers, etc.
device’s physics package and driving devices. They also commented on each technology’s ESL matrices regarding technical performance capabilities for environmental conditions. An example of a proposed technology’s current and future environmental and SWaP capability is presented in Figs. 17a, b, and c respectively. Supplier comments have been removed to maintain confidentiality.

C. Q-PNT Technology MAP analysis

The defence and security sectors face the challenge of releasing sanitized information in open literature while retaining necessary technical detail, such as specific technical performance, platform type, and name. Two worked examples are presented to demonstrate how the ESL tool can sanitize such information and provide suppliers with information on the suitability of technology to classified requirements. In these examples, the technology’s known performance is used to define operate and survive functional modalities. For the SWaP matrix, each cell where a technology capability matches a platform requirement is considered an exact match in the MAP-SWaP process. The MAP process is carried out using the requirements captured for platform A (Fig. 13) and platform B (Fig. 14) to assess technology maturity. Fig. 19 and Fig. 20 present the results of the MAP-ESL and MAP-SWaP processes for platform A and platform B, respectively. The ESL matrices are normalized in areas where the technology’s environmental functional capability overmatches the platform requirements, downgrading the operational functionality of value two to survive the functionality of value one.

D. Technology maturity assessment summary

The ESL and SWaP matrices were used to capture the two platforms’ technology environmental requirements, allowing the technology’s environmental functional capabilities to be articulated as a function of the platforms’ requirements.

The MAP process was applied to quantify the technology’s percentage fit to each platform, and the summary data is presented in Fig. 21. The figure shows that the technology’s current environmental capability matches 26% of platform...
A’s requirements and 36% of platform B’s requirements. The predicted future technology matches both platforms’ environments by 70%, but Fig. 20 shows that the technology is fundamentally limited within platform B’s environment and does not meet the platform requirements.

For both platforms, the current technology is TRL+ 4, and the future technology maturity is predicted to be TRL+ 5, as the technology capability and SWaP surpass 50% of the ESL and SWaP requirements. For platform A, the current technology SWaP capability matches one of the platform SWaP requirement options, making it an ideal match for the platform. For platform B, the current technology SWaP capability does not match any of the platform SWaP requirement options, but the proposed future SWaP of the technology directly matches one of the platform SWaP requirements.

Fig. 18: MAP analysis of the technology to platform A

Fig. 19: MAP analysis of the technology to platform B

Fig. 20: Summary of ESL and SWaP Map process analysis. The image shows that the technology’s current environmental capability matches platform A’s requirements by 26% and platform B’s by 36%. The image also shows that the predicted future technology matches platform A and B’s environments by 70%. However, it has been shown (Fig. 20) that the technology is fundamentally limited within Platform B’s environment and does not meet the platform requirements.
The ESL matrix and MAP process identified that the technology is unsuitable for platform B due to the platform’s unmounted shock survival requirement. Further investigation was carried out to assess supportive interventions and their impact on the device’s SWaP to avoid a future roadblock. The tools and methodology applied highlighted a significant disparity between the two platforms, with the research proposed increasing the technology’s maturity for platform A by 44% and for platform B by 36%. The results suggest that further research and development should aim to increase the technology’s environmental functional capability, particularly in robustness to platform climatic change, unmounted shock, tilt, and electromagnetic radiation.

E. Tool usability evidence

For a tool to be successful, it must be easy to use and provide a unique and impactful capability. The Q-PNT research call invited suppliers to submit research proposals that supported the development of the next generation of PNT capability. These proposals included developing novel concepts and prototype hardware, testing Commercially available Off-The-Shelf (COTS) hardware, and developing sensor models. Prior to the release of the Quantum Augmented PNT research call, no information on the ESL tool was externally released to Dstl. Therefore, the first time suppliers were exposed to the tool was through the information released in the research call. A panel of DASA SME assessors deemed nine proposals involving the development of hardware prototypes fundable. Of these, seven correctly used the ESL tool within their proposals to articulate technology capability. Hence, 78% of suppliers correctly used the ESL tool without prior knowledge or training.

F. Global outlier identification

The Engineering Severity Level (ESL) matrix provided a simplified visual representation of platform requirements or technology capabilities. During the Q-PNT research call, two proposals, referred to as proposals X and Y, stood out as potential point anomalies. Proposal X proposed a prototype with much greater initial environmental robustness than anticipated, while Proposal Y proposed a significantly higher technology capability increase over a five-year timeframe than other proposals.

Quantitative analysis was conducted on all received proposals to investigate these anomalies. The current and future technology operate capability profile values were deduced and compared. Additionally, the proposals were also compared to the ten platforms’ operate requirement profile values.

Proposal X had the highest initial technology operate capability value but the lowest increase in overall operate capability values over the five-year period. Proposal Y had an average initial technology operate capability value, but the greatest increase in technology operate capability value over the five-year period. The SWaP fit of the prototype to the platform SWaP requirement was also considered.

Proposals X and Y had a MAP-SWaP analysis that fit both the current and future SWaP platform requirements, while the other proposals, on average, only met the SWaP platform requirements with the future proposed technology.

The global outliers identified may have resulted from the ESL matrix not capturing space-based or high-velocity ballistic platforms or from overconfidence bias in the ability to deliver by the technology suppliers. The Q-PNT research call requested proposals for TRL 4-6 technologies, and all proposals submitted met this requirement. However, incorrect assessments of a technology’s capability could result from a lack of understanding of the technology or overconfidence bias by the suppliers. In one instance described above, it was concluded that developer overconfidence bias was the dominant factor for the anomaly. Currently, only a few, if any, tools provide an effective means for identifying this bias.

V. DISCUSSION AND CONCLUSION

This paper summarizes the challenges of using the TRL classification for assessing technology development and presents alternative methods to overcome its shortfalls. One of the significant challenges of the TRL tool is its subjectivity and lack of linkage to real-world outcomes, making it difficult to quantify the technology maturity development life cycle and the resources, risks, and degree of difficulty to transition through TRLs. To address these challenges, a multi-functional technology-maturity classification approach and tool was developed, which uses platform environmental parameters and characteristics to quantitatively classify technology maturity as a function of technical capability within an operational environment.

The ESL and SWaP matrices and MAP process have been created to provide a simplistic and standardized tool for developers to classify technology maturity as a function of a final real-world application. The tool has demonstrated rigour as a basis for redefining the TRL classification definitions, creating the TRL+. The DSTL Quantum Sensing Project has adopted the ESL tool and TRL+ classification, which has shown the ability to articulate a technology’s environmental functional capability and SWaP as a function of real-world use cases. The ESL tool provided evidence to quantitatively classify current and projected technology maturity, identify potential supplier overconfidence bias, and early roadblocks for the future integration of technology into platforms.

The proposed ESL technology maturity assessment tool is easy to understand and does not rely on technology SMEs having deep knowledge of platform requirements for operational environments. It can articulate technology maturation to collaborators, project managers, and investors in a single visual form, and easily identify areas that can be developed, technology mismatches, or roadblocks early to avoid wasteful time and expense. The tool has highlighted specific areas of research and development that would have the most benefit in producing a functional technology, enabling project managers and investors to allocate resources and assess associated risks for transitioning the technology through TRL+ maturity levels.
The ESL and SWaP Matrix and MAP process have demonstrated their potential to improve technology development timeframes and return on investment within the Defense and Security sector if applied as a standardized metric. Further development could enable more widespread use of the approach to support project requirement setting, technical proposal comparison, and project compliance. For example, the current ESL is hardware-centric, and it is recommended that the methodology of capturing requirements and capability in a single dataset be tailored to support the development of algorithms and software.

Currently, no evaluation tool exists to quantify the degradation of technical performance as a function of the operational environment. It is recommended that the technical performance of the technology be represented in terms of technical accuracy as a value score to understand the degradation within a system over time and provide a complete picture of a technology’s true maturity in the intended environment.

The ESL tool methodology could be developed further to support requirements setting, technology development validation and verification compliance of project delivery by integrating a standardized testing regime. A testing criteria range that incorporates laboratory to platform testing and links to the Defense Environmental Handbook testing regimes and Mil-Spec commonly used within the industry could be established. By developing a standardized ESL test and evaluation methodology, international efforts to overcome current challenges in developing next-generation sensors to operate outside of a laboratory environment could be unified in the context of developing quantum sensors.

In conclusion, the TRL classification has limitations in assessing technology development, and alternative methods have been developed to overcome its shortcomings. The proposed ESL technology maturity assessment tool offers a simplistic and standardized approach for quantitatively classifying technology maturity as a function of a final real-world application, providing evidence to allocate resources and assess associated risks for transitioning technology through TRL+ maturity levels. Further development of the tool could enable more widespread use and support project requirement setting, technical proposal comparison, and project compliance. The tool has demonstrated its potential to improve technology development time frames and return on investment, particularly in the Defense and Security sector, by overcoming additional challenges faced due to the classified nature of technical information on use-case environments.

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