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Technology Maturity Assessment Model for Assisting Product Innovation and Development

Research Proposal

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CHAPTER I: INTRODUCTION

1.1 Motivation

Technology readiness levels (TRLs) are a beneficial tool for technology strategies when assessing the advancement of a technology and how close to realisation that technology can be implemented. The TRL measurement was established in the 70s by NASA as a technique for valuing the maturity of technologies for complex system developments for space applications. The TRL scales from 1 to 9, with 9 being the most mature technology, and the discrete levels facilitating the examination of concepts, requirements, and demonstration capabilities.

The usefulness of a maturity tool enables a quantifiable benchmark, risk management, and funding decision for many technology focused companies. It enables the provision for decision-makers to decide whether and when to integrate a technology into a larger system.

The modern business environment is more interconnected than ever. A network of entities generates values within the business world, with customers taking part in the planning, development, and financing of technology and technological driven services. Traditional industry barriers no longer exist and now entail cross-national, cross-industry, and multidisciplinary consortiums to claim and maintain a competitive edge. There is decreasing value on a single technology and single service. SMEs must adapt to become fast, flexible, and agile. Market shares are not simply granted just because a business is well established. Even large corporations must develop a start-up mindset that promotes constant innovation.

Whether a start-up, establish multinational corporation, or SME, technology focused businesses require a uniform, methodical, and widely accepted approach to manage innovation, reduce market risk, make intelligent investments, and determine product markets. One of the most important instruments for supporting technology decisions is the technology readiness level. TRLs are primarily concerned with the incremental creation of technology made possible through R&D practices.

1.2 Research Problem

Since the publication of the TRL scale, the metric has been widely adopted into many industries beyond space engineering but often lacks the rigour for true validation. Engineers and technology managers often over or underestimate the maturity of a technology, which can have costly consequence during product and innovation development, both in monetary value and in time scale.

TRL measurements has several limitations attached to the scale.

- Readiness level does not automatically associate with the relevant or technological maturity.
- A mature technology may influence a higher or lower grade of readiness depending on the distinct system environment. However, this often isn't considered.
- Multidimensional factors must be respected for true value.
- The standard TRL model often neglects adverse and undesirability factors.

Despite the limitations, TRL measurements have their place when considering an innovation or new technology for future products.

- They provide a common understanding of the technology status.
- Improve understand and develop risk management strategies.
- Assist in decision considerations for technology funding.
- Support the decision factors concerning transition of technology.

The proposed research will be assessing influential factors associated with technology maturity and a company's technology objectives and incorporate these considerations into a TRL model.

1.3 Research Question

To establish a rigorous TRL validation model, the following research questions are defined:

1. How does a rigorous validation model predict a technology readiness level compared to the standard TRL scale?
2. How does the model impact the drive for technology maturity?

1.4 Aims and Objectives

This research aims to implement a technology metric management tool that employs a logic algorithm associated to a series of specific closed question relating to each TRL category to provide a TRL validation with supporting evidence. The application of the tool is to discover technology opportunities and challenges, and to improve the decision for innovation processes and performance outcomes in complex engineering projects. The tool will be developed in MATLAB with graphical user interface that will output a PDF document summarising the TRL level and provide a framework to help translate the innovation into a development strategy with quantifiable data. The method for verifying the tool will involve implementing literature examples and applying the tool through several innovation developments with the assistance of the fellow students who are placed in a wide range of industries and organisations. The intent is to encourage innovation with an understanding of the current readiness status, find gaps in the development, and create a strategy that centres around risk management and financials to provide an overview of transitioning and growth for technologies.

The specific project objectives are as follows.

- Convey a series of close question with a binary output to evaluate the technology readiness.
- Propose a new and novel calculation from the question outputs to logically determine the technology readiness level.
- Create a Graphical User Interface that comprises the above two objectives in a user-friendly application.
- Test the TRL calculator with technologies of known literature estimated TRLs.
- Disseminate the TRL tool to fellow students to gather analytical data.

1.5 Thesis Outline

Chapter two introduces and highlights the surrounding literature of industrial practices for product innovation and development by exploring the key areas including technology innovation, maturity, roadmapping, strategies, and financial impacts.

Chapter three discusses the methodology and ethical considerations.

Chapter four presents the novel maturity model and the associated new hierarchy equation for determining a rigorous TRL evaluation.

Chapter five considers the required work beyond the proposal and concludes this research proposal.

1.6 Considerations for Master of Science Level Research

The purported research discussed in this proposal topic is Master's worthy as the subject focuses on adding new insight to a specific area for the study of technology management. This presents originality by extending the standard TRL systems and intends to apply a new model to assess the level of maturity.

CHAPTER II: PRELIMINARY LITERATURE REVIEW

This chapter provides an overview of the background for this research and supports insight into the key areas by assessing the literature surrounding a wide range of technology innovation, maturity, its links to strategic developments and impacts. *For the purpose of the research proposal, the literature review will introduce and highlight important information that will be expanded upon in the full dissertation.*

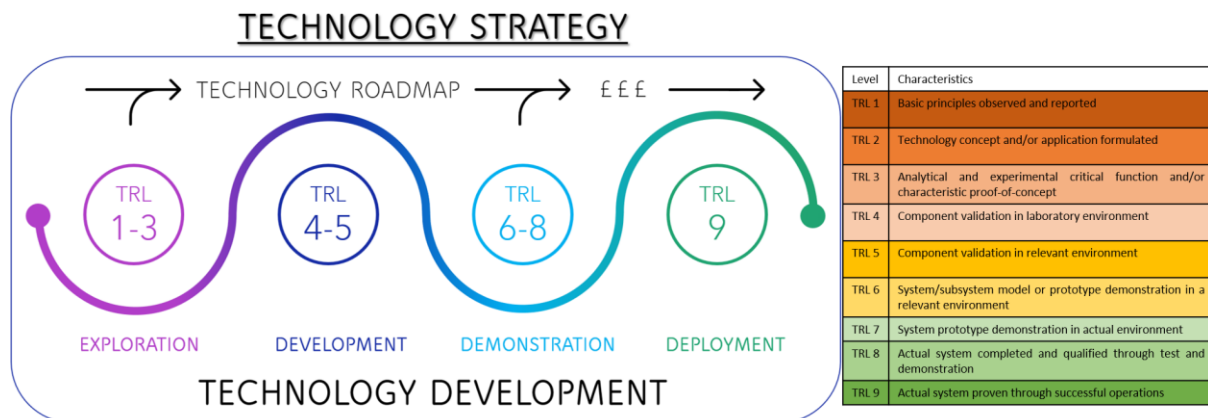


Figure 2.1. (Left) Key considerations for technology strategies with factors around assessment, development, roadmapping, and fiscal. (Right) TRL description table.

To understand the importance of allocating the correct technology readiness level, it is essential to consider the whole picture and how TRLs fit into describing the technology for product innovation. Figure 2.1 presents an infographic that emphasizes the three major components for consideration: roadmapping, fiscal, and development. However, in order to gauge a true direction and strategy, it is important to know the current state of technology readiness. Without true valuation, the process could become costly in time and financially, potentially requiring further development work than initially assigned.

2.1 Technology Development and Innovation

Since 1949, global firms have evolved in terms of technological innovation and technology management, as described by (Xu et al., 1998). As part of a larger enabling policy framework to achieve the millennium development goals outlined in the millennium declaration, the executive summary (Weening, 1990) seeks to identify policies for the effective promotion of science, technology, and engineering for innovation and capacity-building in education and research. According to (Lyytinen et al., 2003), the analysis of IT innovations that display abnormal discontinuities in IT innovation behaviours required the expansion of the innovation theory. For this reason, (Liu et al., 2013) provide a general analysis of the technology innovation process and key participants. For instance, computer science education teaches how to provide pupils with the ability to innovate (Huang et al., 2015). (Park et al., 2018) study aims to analytically investigate the effects of technological innovation on the performance of organisational members in the disaster prevention sector and their resistance to technological innovation. (Omobhude et al., 2019) attempt to examine both spatial and non-spatial factors that impact the development of sustainable technology and innovation, including geographic, cognitive, organisational, societal, and institutional proximity. They reviewed 123 scholarly articles (1980-2018) that dealt with proximity of innovation.

The current economy is being driven by the heavy use of technology on all fronts (Mercado, 2018) as science and technology are developing at an exponential rate. The growth of innovation management as a cross-cutting mechanism to advance various socioeconomic areas, particularly those supported by engineering, is attempted to be exposed in the light of the concerns expressed by

(Mercado, 2019). To address the uncertainties of technology development and policy choices in the biopharmaceutical business, (Chan et al., 2018) offered a research framework to help formulate innovation strategies. The generalised method of moment is used to examine the energy technological innovation drivers, such as energy price, public financial policy, knowledge stocks, energy structure, and environmental regulations, utilising China's provincial panel data from 2001 to 2015 (Yang et al., 2019). Given the innovation development process, (Fernandes et al., 2022) propose some methods and procedures for putting a theory or body of research into clinical practice. Other noteworthy works include those by (Niosi, 2008), (Hu, 2018), (Guo et al., 2018), and (Feng et al., 2021).

2.2 Evaluating Technology Maturity

The findings from the Software Engineering Institute study on the viability of; (a) employing technology readiness levels (TRLs) in science and technology objectives, (b) building or procuring a TRL tool, and (c) applying a TRL tool are described in (Graettinger et al., 2002). (Smith, 2005) propose an extensible evaluation framework that can be used with any type of *non-development item* software. (Dubos et al., 2008) provide an analytical methodology to find acceptable schedule margins for reducing the risk of schedule slippage based on data from previous space programmes. (Mankins, 2009) offer a look back at the development of TRLs during the last 30 years.

Future readiness levels and a future readiness index are proposed by (Botha, 2018), building on technology readiness levels and manufacturing readiness levels. Due to the rapidity of technological adoption in both developed and developing economies, achieving technology-based policy goals within an adequate lead time may provide numerous technological, regulatory, and market-based solutions (Kobos et al., 2018). (Webster et al., 2019) created an institutional readiness model that acknowledges the importance of technological preparedness while also integrating it into a larger socio-technical framework.

A nod to the originally proposed TRL structure, the Kilopower Project was started by NASA's space technology mission directorate/game changing development program in fiscal year of 2015 to demonstrate subsystem-level technology readiness of small space fission power in a relevant environment. This was done to meet the power requirements for space science and human exploration (McClure et al., 2020). (Gil et al., 2020) proposed an evaluation with the following goals; (1) enhancing knowledge of the structure and contents of the academic field relevant to the proposed topic; (2) identifying and mapping scientific networks in the field; and (3) examining and visualising TRLs of an analysed system. (Kumari et al., 2022) contend that there may be a mismatch between legal intent and technical reality, which would result in protected systems that are less effective than they could be and increase the risk of noncompliance. The research aims to address the deficiencies found with existing technology readiness assessments and seeks to solve these by providing a standardised technique suited for evaluating software with respect to its market readiness and quality maturity.

A methodical technique for evaluating the maturity of manufacturing technologies is presented by (Vella et al., 2009). The procedures required to elevate the human systems integration maturity evaluation to the level of technological readiness assessment in the US air force's rapid acquisition programmes are discussed in (Kosnik et al., 2010). A process-driven optimisation approach that incorporates maturity assessment into the "House of Quality" is introduced by (Fomin, 2010). (Sarfaraz et al., 2012) makes use of the maturity artefacts found in system architectural models to lessen subjectivity in TRL maturity assessments. (Islam et al., 2014) work offers a multi-stage methodology for the evaluation of technology maturity profiles. The reliability of technology maturity assessments at a crucial decision stage is examined by (Peters et al., 2017). Other influential work includes (Moorhouse, 2002), (Macdonald et al., 2001), (Redo-Sanchez et al., 2013), (Olechowski et al., 2020), and (Roh et al., 2020).

2.3 Technology Roadmaps and Project Ventures

Technology roadmaps provide the drive to technology and can be guided by the current maturity level. (Kostoff et al., 2001) presents a roadmapping strategy and shows the fundamental coherence of what appear to be fragmented roadmap methodologies. (Schaller, 2001) summarises a review on the International Technology Roadmap for Semiconductors (ITRS). An important global roadmap for innovation in semiconductors that cross companies, countries, and competition. Technology roadmaps' potential to promote virtual innovation and innovation factories is examined in (Rinne, 2004). The fundamental goal of (Lee et al., 2005) is to offer instructions for adjusting technology roadmaps. The goals, specifics of activities, and methods for applying technological roadmaps and roadmapping are shown in (Yasunaga et al., 2009).

(Miao et al., 2022) combined *technology-relationship-technology* semantic analysis and technology roadmapping methods approach to present a framework for monitoring the innovation routes of emerging technologies and identifying future changes and trends in innovation pathways. This may lead to improvements for unconnected and misaligned strategies for related innovation projects, which decreases the risk of ineffective resource usage and lost chances to maximise the return on technological R&D investments. The idea of integrating innovation roadmapping, which is intended to facilitate the systematic integration and alignment of several functional roadmaps, was introduced in 2022 (Ho et al., 2022) to overcome these issues.

2.4 Technology Strategy

(Capon et al., 1987) describe the effects of technological change on corporate behaviour before introducing the technology portfolio and a framework for creating a technology strategy. Managers have received very little information about what technology strategies might entail or what is involved in its deployment, despite the dire warnings about the consequences of failing to address the issue. (Ford, 1988) tried to close the gap by providing the following fundamental information about what exactly a technology strategy is. A paradigm for analysing the interaction between technology, strategy, and structure is presented by (Parthasarthy et al., 1992) in the perspective of existing inclinations toward flexible automation. The strategic alignment framework utilises the Strategic Alignment Model to reflect the idea that the relationship between organisational infrastructure and processes, information technology infrastructure and processes, and business strategy determines how successful a corporation will be (Luftman et al., 1993). The discussion here focuses on topics that are frequently raised in recent writings on international technology transfer, such as the connection between organisational options for international technology transfer and the development of indigenous capabilities within technology recipients, the effectiveness of various organisational options for international technology transfer, the impact of external factors on the results of the international technology transfer process for recipients of technology and policies. These difficulties are looked at by (Cusumano et al., 1994) from the perspectives of both global technology transfer and technology strategy and management. (Lowe et al., 1998) provided a report on a significant UK-wide examination reviewing the role of internal R&D and licencing as alternative and complementary approaches to developing new products and processes.

The relationship between technology and innovation and strategic management is based on three theories of technology and innovation: the product-process idea, the meta-learning concept, and the concept of technical interdependence. (Butler, 1988) pinpoints these theories' coordinating and unifying ideas that are beneficial to strategic planning. According to research on the impact of product innovation strategies on the success of new technology ventures (Li et al., 2001), the relationship between innovation and performance was dependent on both external factors such as institutional support and turbulence in the environment as well as the relationship-based business

strategies employed by the ventures, such as alliances for product development and political networking. There is evidence of complementarity between various innovation efforts described in (Cassiman et al., 2002). Investigating how innovation networks can be used to adapt to a changing technological environment is the goal of (Dittrich et al., 2007). Platform offering, co-creation, cycle time reduction, brand value enhancement, technology leveraging, futureproofing, lean development, partnering, innovation mutation, creative destruction, market segmentation, and acquisition are among the 12 ways of visualising innovation strategies identified by (Bowonder et al., 2010). (Dadfar et al., 2013) investigates a hitherto unstudied relation between organisational innovation capabilities, product development, and performance in Iranian pharmaceutical SMEs. The performance of academic spin-offs can be influenced by incubation support and innovation strategy, according to (Soetanto et al., 2016).

2.5 Road to New Product Introduction

The technology maturity will dictate the developmental drive toward introducing that technology within a new product. The description of a seven-step plan that is intended to take a product from the idea stage to product launch was outlined by (Cooper, 1983). Unfortunately, a lot of businesses continue to use management techniques and organisational structures that slow down product development. (Gupta et al., 1990) investigate the causes, characteristics, and preventative measures of product development delays. Cross-sectional studies of the conduct and effectiveness of new product development were published in 1968 and 1982. The extensive findings of these studies have been widely replicated and used as standards for product development (Page, 1993). However, these objectives could clash, so businesses must consciously weigh the trade-offs involved. A multistage model of the new product development process was introduced by (Cohen et al., 1996) that explicitly incorporates the trade-offs. According to the best practices found, the degree of cross-functional integration and information sharing, the firm's marketing and technical resources and skills, the effectiveness of the new product development activities, and the characteristics of market conditions all have a positive impact on the success of new products (Song et al., 1997). (Song et al., 1997) also created a theoretical framework that investigates how perceived technological uncertainty affects the creation of new products. Businesses may create dispersed innovation models that include a range of customer roles in the development of new products thanks to virtual customer communities. By focusing on four underlying theoretical themes (interaction pattern, knowledge creation, customer motivation, and virtual customer community-NPD team integration), and deriving their implications for virtual customer environment design, (Nambisan, 2002) used a "multitheoretic lens to examine the design of such virtual customer environments". Based on the findings of a multiple regression analysis, (Petersen et al., 2005) found evidence for the correlations for NPD and virtual customer communities. (Battelino et al., 2022) explored the benefits and drawbacks of the various types of research frequently utilised for evidence selection and grading and offered suggestions for improving the procedure to better handle the quick pace of new product development and device innovation. The goal of (Idress et al., 2022) is to explore how knowledge management capacities affect the performance of new product development, with organisational agility serving as a mediating factor. Application readiness levels for NPD activities were produced by (Du et al., 2012) based on the analysis of product maturity cycle and the studies of technology readiness and manufacturing readiness levels.

2.6 Financial Impact for Technology Development

When technology remains in the development phase, the financial cost can be difficult to calculate. In (Taleb et al., 2014), the authors demonstrated how technical-economical cost modelling can assist direct research and development to focus on critical production cost components of new goods based on emerging technologies. To research how a manufacturer's financial limitations affect

a firm and the supply chain when it comes to R&D investment, (Lee et al., 2021) analysed a supply chain where there is just a single manufacturer and single supplier and where the manufacturer has a little window of opportunity for cost-reduction.

CHAPTER III: METHODOLOGY

3.1 Justification for Methodology

The proposed methodology will use a series of closed questions to build a quantitative understanding and perspective of a technology's maturity. The output data will be coded into a binary description. This coding will take place within a purposely develop software package, scripted in MATLAB. The coded data will pass through the hierarchical equation to not only prove a single value for the TRL value but also highlight what areas require improvement and focus in order to achieve a higher maturity level, which in turn should aid product innovation by guiding the strategy.

The advantage to this quantitative method is the ability to "test and check" and it allows a larger reach for sample size. The data can be collected and processed at speed by focusing on factual information. The collected data becomes more reliable and less open to argument, as well as being anonymous. Quantitative methods are less exposed to error and subjectivity. Therefore, taking opinion-based technology maturity out of the equation, which is the current method for evaluating TRLs. Furthermore, quantitative research enables the application of technical advancements such as computational mathematical modelling. The limitation of this research method provides the possibility to overlook broader themes and relationships meaning that the bigger social phenomena picture information could be missed by solely focusing on the numerical allocation.

3.2 Research Procedures

The research procedures will adhere to the following procedures.

1. Identify and develop a series of questions that are bounded by the criteria topics of the hierarchy model.
2. Implement a programmable script for the model based of the proposed equation.
3. Verify the model using literature examples.
4. Produces a sample of case studies from first and third person examples.
5. Interpretate and present the data.
6. Conclude the study.

3.3 Data Collection

The data will be collected from three sources to provide a series of case studies that can verify the rigorousness and robustness of the proposed technology maturity model.

1. Literature – technology that currently has been allocated a TRL value within the literature will be reviewed and processed through the purposely developed software.
2. First person – The author will examine a set a different technology that lie within their expertise.
3. Third person – The authors fellow students will also be asked to process a technology of their expertise.

3.4 Ethical Considerations

Due to the nature of this project with regards to evaluating the maturity of first and third parties' technologies, there are certain ethical considerations that need to be taken into consideration. Participants will be provided the opportunity for anonymity for their companies. Every effort will be made to minimise the technology detail exposure and its relation to the company. Therefore, the proposed software will include features that provides protection and the opportunity for redaction. A strategy of informed consent will be adopted, with the aims and method of this research made clear to all participants.

CHAPTER IV: MODEL FRAMEWORK CONCEPT

4.1 Model Framework

The aim of this research is to determine a rigorous evaluation model for ascertaining technology maturity in the pursuit of furthering product innovation and development. The specific task proposed in the introductory chapter outline a series of closed questions with a binary choice. These closed questions form the measurables of the model that sit within subsection criteria. The binary outcome from the measurable enables a 0 or 1 allocation to each individual measurable that transposes through the hierarchical model and normalises the objective (TRL) with respect to the original TRL numerical scale. A visual representation of the hierarchical model is illustrated in figure 4.1.

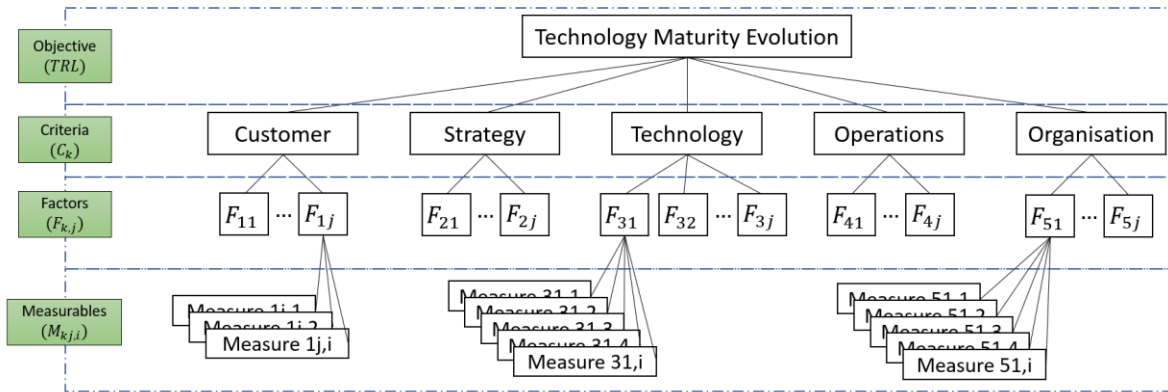


Figure 4.1. The generalised hierarchical evaluation model for determining technology maturity.

4.2 Hierarchical TRL Equation

The proposed equation enables the formation of a rigorous TRL value that corresponds to the current well-known numbering (1-9) system.

$$TRL(n) = 9S_n$$

With:

$$S_n = \left(\frac{\sum_{k=1}^5 \left(\frac{\sum_{j=1}^{n_j} \left(\frac{\sum_{i=1}^{n_i} M_{kj,i}}{n_i} \right)}{n_j} \right)}{5} \right); \text{where } \begin{cases} S_n \leq 1.0 \\ M_{kj,i} = 0|1 \end{cases}$$

Where:

- $TRL(n)$: Technology readiness level value established by the corresponding criteria (C_k) according to the company's technology objectives.
- The value of 9 arises from the maximum value allocated by the conventional TRL scale.
- S_n is the summation of hierarchical model.
- k has a maximum value of 5 due to the set number of criteria (C_k).
- n_j and n_i are the maximum value of the factors and measurables, respectively.
- $M_{kj,i}$ is the relative value of the j_n^{th} and the i_n^{th} conditions with respect to the measurables.

4.3 Example of Output

An example of the visual output from the proposed model for evaluating the maturity of a technology can be found in figure 4.2. The tradition TRL provided only a single digit with little information on how or where to make improvements to raise the TRL. The proposed hierarchal model not only provides this overall TRL single digit (*centre of figure 4.2*) as an average summation of each criterion, but it also highlights the areas for improvement. The example in figure 4.2 demonstrates that the organisation and customers provide value but the operations to implement that technology is serious behind, as is the technology itself.

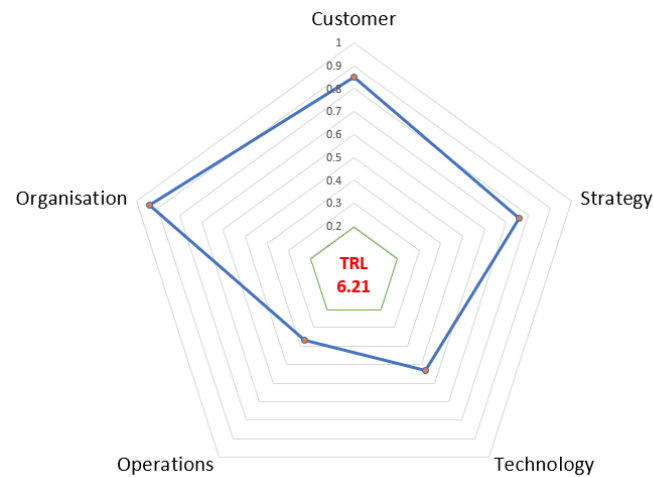


Figure 4.2. An example, with arbitrary values, graphical solution to the hierarchical evaluation model.

CHAPTER V: FUTURE WORK AND CLOSING REMARKS

5.1 Future Works

The Gantt chart presented in figure 5.1 shows the timeline for the various steps for the research discussed in this proposal. The main milestones in this project are as follows:

1. Linking the equation to the series of questions.
2. Implanting this within a software package for user-friendliness.
3. Completing a series of case studies.
4. Completing the write-up of the dissertation.

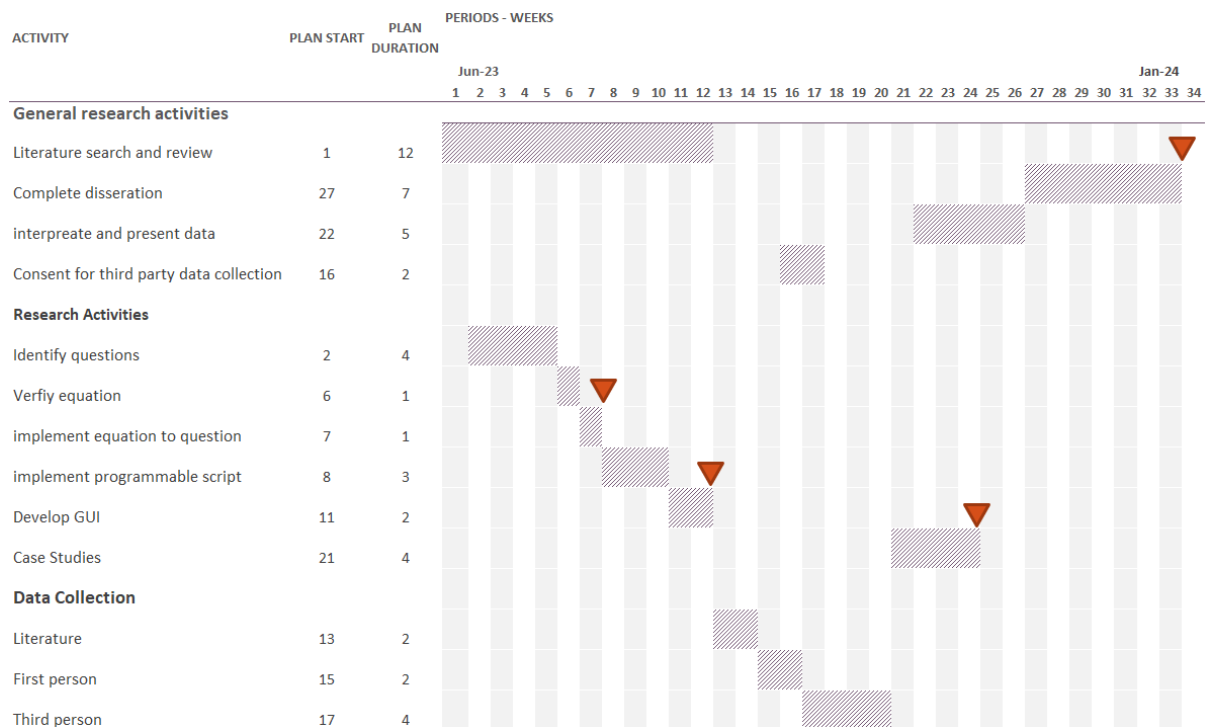


Figure 5.1. Gantt chart for main project activities with the red triangles indicating the project milestones.

5.2 Conclusion

The research outlined in this proposal presents a new and novel method that could provide a rigorous evaluation for determining a given technologies readiness level (TRL) for assisting new product development and innovation. TRLs are a common and useful method for determining how mature a technology is and have been used in many engineering settings since its inception by NASA. Nonetheless, TRLs can be difficult to categorise due to their simplistic description and may lead to an expensive and unfeasible development strategy. The proposed research goes beyond the simple TRL characterisations and offers an in-depth hierarchical solution that includes not only the technology itself, but also the operational, strategic, customer, and organisational requirements that are obligatory to develop a strong strategy for product innovation. The proposed method will incorporate a mathematical model integrated into a software package with an interactive visual component for ease of use. The model will provide its base information from a series of measurable in the form of specific closed questions in order to allocate a zero or one to that given measurable. This numerical allocation will be passed through the hierarchical system and become normalised until a value is reached that provides a maturity score with a familiar zero to nine values. The core data will be provided by analysing literature, and from first- and third-person case studies.

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