Technology Roadmapping and 4IR in Defence: Case of Command and Control Systems

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***Abstract*— It is said that 4IR requires new ways of conducting business, including planning for technological capabilities. Although technology roadmaps have been widely used for strategic technology planning, constructing and customising one for a specific domain is challenging. This study explored technology management processes and support tools for 4IR technologies for the SANDF that can be customised to construct technology roadmaps in C2 systems. Qualitative based interviews were conducted, as a primary data source, with the technology management personnel from the Acquisition agency of the SANDF (Armscor), and official documents from the SANDF, as a secondary data source, were analysed. Content analysis of the interview responses and documents show that various processes, including *identification, selection, development, exploitation, protection,* and *learning,* are used to manage C2 technologies. However, due to users' low understanding of the C2 environment, there is not much technology roadmapping-taking place in C2, especially in Defence. Moreover, 4IR is viewed differently from technology management (human capability), therefore falling outside the scope of technology management, resulting in few technology projects on 4IR. This study contributes to the understanding of a universal toolkit for generic technology management activities by providing confirmation results in a Defence environment.**

Keywords—Technology Roadmapping (TRM), Command and Control (C2), Defence, 4IR

I. Introduction

It is said that the Fourth Industrial Revolution (4IR) will have a disruptive impact on every establishment, government, organisation, industry, sector, and social interaction. 4IR technologies are changing the Defence landscape, technological capability, threat type, and operations execution[1]–[3]. It is changing the nature of conflicts, making them hybrid and involving traditional battlefield actors and techniques that support these advanced technical systems. These emerging digital technologies and systems are also blurring the lines of battles, war and peace, violence, and non-violence.

Fan and Liu [3] postulated that IoT could accelerate the evolution of military applications in modern conflicts. They demonstrated that, with these new technological capabilities, the remote, legacy, disparate and disconnected systems could be linked to enhance the capability and the quality of data used for decision-making in Command and Control (C2) scenarios. Another example is robotic weapons and unmanned aerial vehicles (UAVs) used in armed conflicts for target detection, acquisition, and engagement. For instance, the SGR-A1 robot, equipped with two machine guns and a rubber bullet gun, was used to monitor Korean Demilitarized Zone order posts [1]. The Council for Scientific and Industrial Research (CSIR) is also exploring 4IR technologies for C2 field operations for the South African National Defence Force (SANDF) [4]. They experimented with future C2 deployment scenarios over the next generation mobile networks (4G and 5G). Their study demonstrated a highly connected C2 deployment in field operations, underpinned by 4IR technologies, including drones, IoT, and capabilities such as machine-to-machine communications.

However, Defence, including SANDF, faces many challenges that cause technology projects to be re-prioritised and others to be cancelled [5], which negatively impacts its capability. The SANDF must maintain and enhance its technological capabilities and operations despite challenges. Therefore, it must develop innovative approaches to manage its technologies to cope and be effective in this changing Defence landscape.

Driven by new and emerging technologies, 4IR requires organisations to transform their production, management, and governance systems, and therefore, new business and technology strategies will need to be developed [5]. Technology Roadmaps (TRMs) are technology management tools used in many industries, sectors, and governments [6]–[8] to provide a strategic framework for technology planning, and their flexibility enables them to be used in technology evolution and revolution, such as in the case of 4IR technologies [9].

Although TRMs are versatile in their application, constructing a TRM is challenging [10]. It involves identifying, selecting, and planning candidate technologies development. TRMs use technology management techniques and tools that should seamlessly integrate with the processes and systems of the organisation for streamlined and strategic management of technology. Such a problem is exacerbated by the decision-making activities that usually accompany the development of a TRM, which requires statistically robust and academically sound methods, techniques and supporting tools. Robert Phaal [11] emphasised that technology

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management focuses on informed decisions about technology investments and deployments.

This research aimed to explore technology management in the Defence industry, focusing on C2 technologies, to identify TRM methods and tools (in the form of a toolkit) used for technology planning in the 4IR context. A toolkit is seen as a carefully selected set of technology management tools used for technology management methods and activities to plan technological capabilities or systems. For example, tools used to analyse the organisation's threats, opportunities, strengths, and weaknesses [11]. In addition to the toolkit, this study contributes to developing a universal toolkit for generic technology management activities, as proposed by [10]. Therefore, the research seeks to address the following questions: Firstly, what is the nature of the TRM for C2 technologies in the South African Defence, with regards to technology management tools, stakeholders, and their interactions? Secondly, what are the current TRM challenges for C2 technologies in the South African Defence? Lastly, what are the perceived TRM challenges for C2 technologies in 4IR for South African Defence?

II. LITERATURE REVIEW

This section presents an overview of 4IR, including its driven technologies, technological impact, and coping mechanism, focusing on the Defence domain. In addition to 4IR, the studies on technology management, methods, and support tools are discussed. In particular, technology roadmaps and roadmapping in a revolutionary environment such as that brought by the 4IR.

A. *Fourth Industrial Revolution*

Industrial revolutions precede the 4IR [12], the first industrial revolution started at the end of the 18th century, and it was driven by water and steam technology to mechanised production in manufacturing. The second started at the beginning of the 20th century and introduced electricity, electric motors, railways, and subsequently enabled mass production (Example: assembly lines in manufacturing). In the late 20th century, the third industrial revolution introduced digital systems such as electronics, telephones, computers, mobile and smart devices, and subsequently automated production processes. Schwab [13] defined the 4IR as the technology change characterised by the fusion of technologies that integrate digital, biological and physical spheres, and its scale, scope and complexity, revolutionising these technologies at an unprecedented exponential rate. This technological era is driven by radical new and emerging technologies such as Artificial Intelligence (AI), Internet of Things (IoT), 3D printing (for additive manufacturing), nanotechnology, Augmented Reality (AR), Virtual Reality (VR), biotechnology, blockchain, cloud computing, biotechnology, material science, energy storage, quantum computing. [13]–[15].

Organisations are also changing business models and operations to adapt to the changes brought by 4IR while also taking advantage of the 4IR technologies and systems. One example is a high-tech company that changed its recruitment process to adapt to the 4IR requirement [16]. According to this company, 4IR also requires skills and competencies such as creativity, problem-solving, and conceptualisation. ZVEI [17], a manufacturing company from Germany, developed a reference model for 4IR called Reference Architectural Model (RAMI) 4.0 that incorporates diverse user perspectives and promotes shared understanding between stakeholders for 4IR in manufacturing. However, the RAMI 4.0 was designed for Industrie 4.0 (manufacturing), and it cannot be easily employed in other sectors without modification. Therefore, there is a need for a simplified implementation framework that supports the management and development of 4IR technologies, particularly in a Defence context.

B. *Technology Management*

Cetindamar et al. [18] define technology management as activities that "include planning, directing, controlling and coordinating the development and implementation of technological capabilities so that firms can shape and accomplish their strategic and operational objectives". To this end, they proposed technology management activities, support tools and a framework in which they interact, see Table I.

TABLE I. TECHNOLOGY MANAGEMENT TOOLS AND ACTIVITIES [18]

Technology Management Tool	**Tool Description**	**Mainly used in these activities**
Patent analysis	Tools used to translate technology patent information into useful metrics for technology management decision making	Acquisition Protection
Portfolio management	Integrated management tools used for two or more projects, grouped according to some criteria	Learning Section
Roadmap	Graphical charts or tools that are used to map technology projects expected outcomes and milestones from the current period to the desired state in the future	Exploitation Learning
S-Curve	A tool used to determine or predict the life cycle of a technology, product, or industry	Exploitation Identification
Stage-Gate™	A management tool used for new product development (Cooper, 2017) employs a stage-wise process consisting of decision points called gates to assess set milestones and track progress.	Identification Protection
Value analysis	Tools and techniques used to assess the perceived value of a technology or product in accomplishing its intended objectives relative to alternatives and strategic objectives	Acquisition Selection

TRMs are popularly used as frameworks for strategic technology planning. In other words, they are used as platforms for other tools to interact.

C. *Technology Roadmapping*

TRMs tools are used in many sectors and industries for technology management applications such as identifying, selecting, planning and forecasting [11]. A TRM can be a chart that maps the technology projects to technologies, products, businesses and markets (See Fig. 1). In addition, TRMs can be formatted to fit the purpose of the intended application [19].

TRMs align an organisation's mission vision with technological requirements. A standard TRM is a two-dimensional chart of hierarchical layers on the vertical axis and time on the horizontal axis. The hierarchical layers represent organisations' hierarchical decisions about the markets, business, products and services, technologies, and projects [20]. Each layer on the chart has a milestone and addresses three main questions; knowledge (Know-how), know-what, and know-why. The time axis represents the period for each milestone from the past to some point in the future. TRMs are developed through a roadmapping [19], a multiphase process involving planning, development and action plan stages.

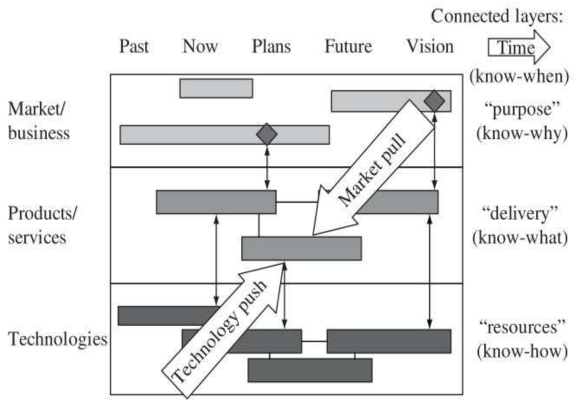

Fig. 1 Generic technology roadmap format [19]

Phaal, Farrukh and Probert [10] proposed a T-Plan or fast-start approach framework. The T-Plan defines four phases (facilitated through workshops) with specific objectives corresponding to specific TRM layers. This framework resulted from a research program through a collaboration between companies and industries to develop industry technology roadmaps. The T-Plan method can be customised and scaled for a specific application and scope and was demonstrated in eleven sectors for different business objectives [10]. For instance, it has been used for product family planning in the security sector. These demonstrations employed case study methods in disruptive technological trends, both at a company and multi-organisational levels [21], [22]. However, this workshop-based method does not provide a practical guide on using technology management processes, methods, and tools. It only identifies the objectives for each workshop and the associated outcomes. It does not give systematic and practical guidance on the decision-making process in each phase. Hence, no provision for the identification and selection of supporting methods and tools.

Johanna et al. [19] developed a systematic guide to facilitate the construction of TRMs called SyTRM. Unlike the T-Plan method, the SyTRM provides detailed systematic procedures to guide the roadmapping, including identifying technology management methods, techniques and supporting tools. Similarly to the proposed roadmapping phases [23], the SyTRM consists of three phases: planning, construction, and generation of new projects. In addition, the SyTRM is scalable to include several layers in the roadmapping process. Fig. 2 shows a snapshot of the SyTRM.

Like the T-Plan, the construction phase of the SyTRM consists of four layers and allows for results evaluation from each layer activity (shown with rhombus symbols in the figure). Hence, enabling the identification of decision-making points. For example, it was tested in the motor vehicle manufacturing setting, where appropriate methods and tools were used to create a roadmap for the technology evolution of an electric car [19]. However, unlike the T-Plan method, which does not identify processes and supporting tools but only the stages in the roadmapping process, the SyTRM proposes tools and processes for these activities.

Academics have explored the idea of a flexible and universal toolkit for generic technology management activities. Phaal, Farrukh and Probert [24] argue that developing technology management tools is a multi-disciplinary task requiring all stakeholders' perspectives, including industry and management. They proposed that the 2x2 matrix-based tools (linked list-based tools) can be suitable candidates for the universal toolkit. They investigated 850 matrix-based tools and classified them according to flexibility, robustness, and integration ability.

In another study, Kerr et al. [10] also appreciated the challenge of identifying, selecting, adopting and integrating individual technology management tools that can be seamlessly used with the organisation's processes and systems to manage technology. Seven principles to guide organisations in deciding on the nature and characteristics of the tools that can be included in the technology management toolkit for TRM are recommended (See Table II).

TABLE II. TECHNOLOGY MANAGEMENT TOOLKIT SELECTION PRINCIPLES

Attributes	Description
Human-centric	allow people involved in strategic technology planning to collaborate in the formulation of the solution
Workshop-based	use of workshop as a platform for engagement and deployment of the toolkit in specific application usage for solving strategic problems through structured activities
Lightweight processed	the tools should enable a process to be flexible and should enable application in a lightweight manner based on the premise of "start small and iterate fast."
Neutral facilitated	These workshops should be facilitated by a neutral person, i.e., facilitation of the process and not involved in the content
Modular	Tools should be built or selected such that they can be integrated.
Scalable	it should be possible to deploy the tools at any level of the roadmap, i.e., provide a scalable hierarchy
Visual	the tools should provide a visual representation during the roadmapping and the resulted output

Phaal et al. [11] also explored a "workshop" based system as a possible approach toward developing a flexible toolkit for technology management that could be used in strategic technology and innovation management challenges. This approach includes identifying functional modules based on these seven principles to address technology management issues.

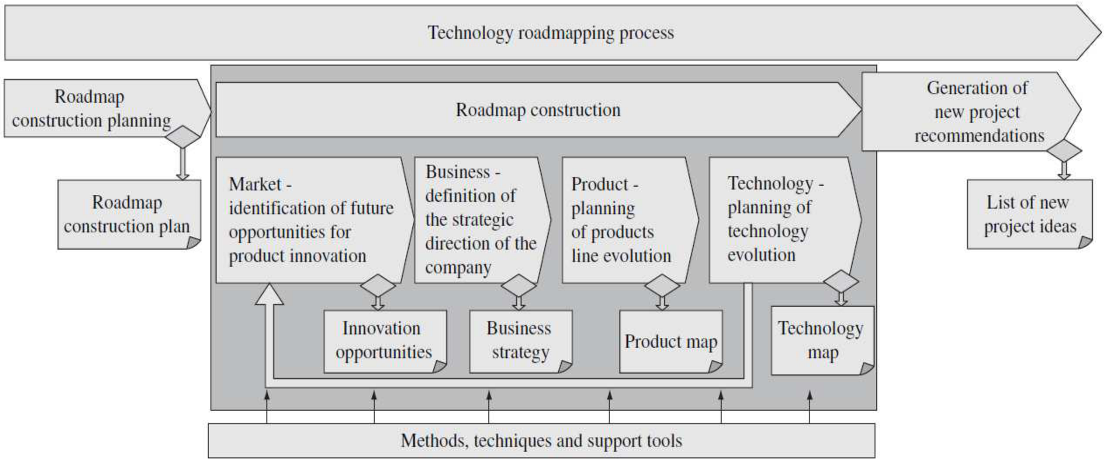

Fig. 2 SyTRM framework process [19]

As stated earlier, TRMs are used as technology planning frameworks for other technology management tools. However, the construction of a technology roadmap has been seen as more art than science. Therefore, there is a need to develop scientifically robust, academically sound, and integrated TRM tools and methods that adapt to specific applications or problem domains. Researchers have proposed frameworks for identifying the technology management activities and methods to provide associated guidance on the development of TRMs. However, these frameworks were applied and tested, primarily in manufacturing [19]. This research aimed to adapt these frameworks in a Defence setting and identify technology management methods, challenges, and supporting tools for C2 technology management in 4IR.

III. Methodology and Methods

A. Research Conceptual Model

The SyTRM and the seven principles were used to frame this research and adapted for the Defence setting to inquire into C2 technology management methods and support tools. The SyTRM was used as a data collection framework for addressing the research questions. The seven principles of a technology management toolkit were used as a selection criterion for the technology management tools. The conceptual model used in this research is shown in Fig. 3.

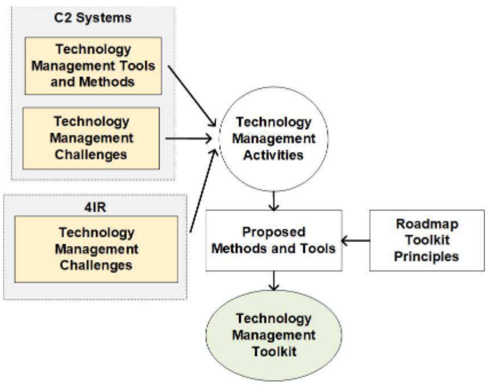

Fig. 3 Research conceptual model

The objective of this research was to identify the technology management methods and support tools for C2 systems in a Defence setting. In the figure, the conceptual model's technology management methods and tools element was based on the SyTRM methods and support tools to provide a base for inquiring and addressing the first two research questions, i.e., identifying technology management methods and tools and associated C2 challenges. In addition, this research focused on the C2 technology systems underpinned by the 4IR technologies; therefore, the 4IR element of the conceptual model indicated the third research question, i.e., identification of technology management challenges for C2 technologies in the context of 4IR.

B. Research Design and Methods

This research focused on the technology management experiences of the people charged with technology management for C2 Defence technologies. Therefore, a qualitative study was adopted because it is concerned with data collection and analysis techniques for non-numeric data types, such as those generated by interviews, documents, archives, and pictures [25]. Furthermore, an exploratory inquiry approach was used to gain familiarity with the phenomenon or get new understandings [26].

Although the conceptual model used in this research combined multiple concepts or theories, this research tested whether the proposed theoretical framework and concepts are applicable in Defence. Therefore, a Deductive Theory Testing approach was adopted to test the theory from collected data [26], [27].

A case study as the data acquisition strategy was adopted to gain insight into the phenomenon. A case study is suitable for "gaining a rich understanding of the research context and the processes being enacted" [25]. This research study was based on a single and embedded case study, i.e. represented a sub-unit within a critical, extreme and unique single case [28]. The SANDF is the only Defence force organisation in the country. Hence, the management of its resources, including technology, was considered unique. Moreover, C2 is one of the technology areas in the SANDF, among Cyberwarfare, Radar Electronic Warfare (REW), and Landwards. In addition to the uniqueness and embeddedness of the case, this research aimed at gaining a deep understanding of a unique organisation with sensitive information; hence the case study approach was deemed suitable.

Data were collected using two data collection methods: interviews (primary data source) and official archived documents (secondary data source). Semi-structured interviews were used to enable a guided approach and ensure consistency in asking the questions during the interviewing process. The interview questions were developed guided by the technology management activities proposed by Johanna [19] to address the main research questions of this research while also providing for open engagement to gain insight into the technology management activities. In addition, these interviews were conducted face-to-face to establish rapport between the researcher and the respondent [29]. Hence, improving the chances of gaining insights and for respondents to be open about sensitive issues. Initially, it was planned to interview only people from the case identified through personal contact. However, as the interview continued, the interviewed participants recommended SANDF technology representatives who could share some light on the subject matter. Recordings during the interviews were archived into a secure server under password protected file systems to prevent unauthorised access. Participants were notified of how the collected data would be archived and protected.

A convenience sampling based on specific criteria was used. This strategy is preferred for small sample sizes case studies to identify data, participants, and sources [28]. This research adopted Stake's [27] view of a case study, where a small number of cases or samples are used. Ten interview requests were sent through email to potential participants that met the selection criteria of a two-year minimum experience in the technology management department or related tasks. Four people responded to the requests (40% response rate) and agreed to participate in the research and be interviewed face to face. These respondents had between two and eight years of experience in the technology management aspect for the SANDF across several technology areas, including C2 technologies.

Armaments Corporation (ARMSCOR) is a South African state-owned company mandated to perform acquisition services for the SANDF. The SANDF and ARMSCOR jointly manage technology development under the guidelines of the Ministry of Defence. These guidelines are promulgated in the form of Policy documents, handbooks, and related technology development directives. Therefore, these documents were seen as a rich source for understanding the technology development system of the SANDF and as a framework of the technology management processes for identifying technology management tools and their usage in the technology management activities for Defence. They were selected based on validity and relevance (not more than ten years) to the current technology management practices in the SANDF and their availability for the research.

Content analysis was used to analyse and categorise the collected data into proposed technology management activities identified in theory [19]. The intent was to explore and identify technology management activities performed in the Defence to achieve the set goals of C2 technology management. Thirty-seven codes were defined and further sub-categorised into twenty-four codes for technology management activities, six codes for the tools and seven codes for the attributes of the technology management tools, based on the technology management toolkit principles [10]. This content analysis was performed based on the interview text data (transcripts) and the identified documents. The coded data was generated by analysing each sentence in the textual data and categorising it into codes, and coded data were clustered to identify technology management themes. Moreover, unique codes were used to identify the data source in the transcription process, and the participant's identity was disguised in reporting the results.

IV. FINDINGS

A. Technology Management Tools

Table III shows the aggregated technology management processes and supporting tools identified from the interviews and the documents. The results show that Defence, in this case, SANDF, manages C2 technology through a variety of technology management processes and tools [18][19]. The tools used are human-centric, and some are preferred more than others; therefore, they are used in many processes. In particular, the principles of those tools are applied across several processes—for example, portfolio management, value analysis, and roadmapping. In addition, most of the processes are facilitated through a stage-gate process (lightweight three stage-gate) in the form of steering committees.

However, the acquisition activity is viewed as separate from technology research and management. According to the case, technology research and management extends to technology demonstrators (proof of concept); from then onwards, the acquisition activity takes over if the user has a matching requirement. In addition, TRL tools are used to assess technology maturity and define the scope of technology research and management [30].

On the other hand, few people from the user aspect understand the complex environment of C2. As a result, the user has limited involvement or contribution (C2 commanders and military personnel) and management toward roadmapping C2 technologies. Most of the C2 research, development, and vision is led by partner research institutions.

The research reinforces higher management support in strategic technology management in Defence. The lack of support from management and end-user can lead to ineffective technology management practices. Moreover, it emphasises that strategic technology management is a multi-stakeholder and multi-disciplinary activity [11][24].

B. 4IR Challenges

Major challenges for technology management include lack of funding and experience resources, adherence to lengthy regulations and laws, and lack of senior management support. For example, finance is one of the reasons for technology research and development projects not reaching stages where they can be used in operations or be commercialised. Moreover, experienced personnel are retiring, and the new people have little or no experience managing Defence technology. In addition to the limited experience, they have limited exposure to the Defence operations, making it difficult to match the user requirement with the emerging technologies. This led to a few technology areas not pursuing research in 4IR.

The 4IR technologies are viewed as outside technology management and research. They are considered at an advanced development stage, while technology research is considered to be in the primitive stages of development. Consequently, technology management methods and support tools are not modified or adapted for 4IR technologies.

TABLE III. SA DEFENCE MANAGEMENT TOOLS AND METHODS

	Identification	Selection	Acquisition	Exploitation	Protection	Learning
Processes/Methods	Technology audits Forecasting technology markets Markets and external environment Organisational Capabilities Documentation and Dissemination of the information	Strategic analysis Strategic choice and implementations Other (Expert Judgement) Pilot studies	Internal R&D (Portfolio Management) Internal R&D (New Product/Service Development) External R&D (Contracting or Subcontracting) External (Alliances)	Commercialisation Utilisation Technology Transfer	IP Portfolio Management Managing IP and Open Innovation/Technology Collaborations	Managerial (Building and utilising networks) Managerial (building learning/knowledge management) Organisational (Learning Organization)
Tools	Portfolio management Roadmapping Value analysis Stage-gate	Portfolio management Roadmapping Stage-gate	Portfolio management Stage-gate Value analysis	Patent Analysis Value analysis Portfolio Management	Portfolio management Value analysis Patent Analysis	Roadmapping Value analysis
Tools Attributes	Human-centric Workshop	Human-centric Workshop	Human-centric Workshop	Human-centric Workshop		

In addition, 4IR is understood to be advanced technology modules that can integrate to meet real operational requirements. At the same time, technology research is unknown; primitive technology research can be demonstrated in simulated or controlled environments.

C2 is one technology area that conducts research in the 4IR technologies. However, due to the lack of involvement from the user, there is no technology roadmapping for C2, including 4IR technologies.

V. CONCLUSION

This study explored technology management methods and support tools for C2 in the Defence, focusing on TRM for 4IR systems. In addition, this qualitative case study also investigated technology management challenges for Defence C2 technologies in the context of 4IR.

Defence employs various technology management activities, including identification, selection, development, exploitation, protection, and learning. However, C2 planning gets minimum support from higher management, and as a result, there is no or minimal technology roadmapping-taking place. Moreover, the research shows that the technology management tools for Defence C2 are inadequate for C2 4IR technologies. Defence C2 is a less understood technological area in the SANDF than other technological areas.

A. *Study Implication*

The study confirmed that the proposed technology management framework, methods, and support tools are also applicable to the Defence setting [18], [19]. To this end, it contributes to developing a universal toolkit for generic technology management activities [31]. However, none of the technology management methods and support has been modified for 4IR because Defence is not actively pursuing 4IR. Should Defence intensify its technology research on the 4IR, these technology management methods and the supporting tools will need to be modified. Moreover, the 4IR presents new challenges for technology management., such as short-term planning and rapid technology changes, which are different from the usual long-term view of Defence technology research and development.

Furthermore, the results show that Defence views technology management based on human capabilities and at lower TRL (TRL4), while 4IR was viewed as being at higher TRL. This means that 4IR falls outside technology management activities. In practice, these different views of the 4IR and technology management of C2 in Defence can cause a disconnect between the development of 4IR systems and technology research as they are managed separately and by different departments. For managers, this implies that there should be an alignment between these activities to ensure that the skills acquired through technology research are also appropriate and adequate for 4IR systems, Emphasising the need for collaboration between 4IR and technology managers.

B. Limitations

Although the research inquired into the South African Defence technology management, the results are based only on C2 technologies within that Defence. In addition, Defence technology management systems involve several entities, including the Defence industry and research partners. Many of the participants in this research were from Armscor; therefore, the results presented here are from a single entity. Moreover, since this research was based on a case study, the results obtained cannot be generalised. Therefore, they are most valid for the unique case study herein. This research aimed to gain insight into a specific case.

The research objective was to identify tools and methods used for roadmapping in the Defence for C2 systems. However, although some participants have been involved in roadmapping activities for the Defence, they were not part of the construction but, to some extent, involved in the planning and data collection phase of the roadmapping process.

Another limitation of the study is the small size of the interviewees. This can be attributed to a lack of understanding of the C2 technologies in the Defence. Therefore, limited personnel are responsible for the strategic planning of C2 technologies. Nevertheless, this research forms a basis for further research into TM tools for 4IR technology management in Defence.

C. Future Research

It is recommended that future research should include participants that are actively involved in the roadmap construction phase. These participants will share insights into the construction phase, tools, and configurations during roadmapping. Future research should also include running workshops with the relevant technology stakeholders to design, configure and customise roadmapping tools [11] if they are to be used for 4IR technology management. This might require a different research methodology and collection methods, e.g., Focus Groups.

Moreover, future research should consider extending the sample size to other technological areas of the Defence to gain insight and understanding into the strategic technology management processes, particularly TRM, to identify other limiting factors in the application of TRM for C2 technologies. In addition, developing technology management tools is a multi-disciplinary task; future work should involve other Defence technology management communities such as the research institutions and the Defence industry.

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