Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

Technological Capability Assessment and Model Development in Research and Development Center (The Case of Manufacturing Technology and Engineering Industries Research and Development Center in Ethiopia)

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment for the Degree of Master of Science in Industrial Engineering

By: Tereda Tafesse

Advisor: Dr. Gezehagn Tesfaye

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By:

Tereda Tafesse

Approved by the Board of Examiners:

Dr. Gezehagn Tesfaye	______________	_______________
Advisor	Signature	Date
Dr. Kassu Jilcha	_______________	_______________
Internal Examiner	Signature	Date
Dr. Yitagesu Yilma	________________	July 2023
External Examiner	Signature	Date
Dr. Araya Abera	_____________	_____________
School Dean	Signature	Date
Dr. Sosina Mengistu	_____________	_____________
Associate Director For PG Program	Signature	Date

DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "**Technological capability assessment and model development in research and development center: The Case of Manufacturing Technology and Engineering Industries Research and Development Center in Ethiopia**)" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

__________________________ _____________________

Tereda Tafesse Date

(Candidate)

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

__________________________ _____________________

Dr. Gezehagn Tesfaye (Advisor**)** Date

DEDICATION

This thesis is dedicated to my father Tafesse Shirkko, who passed away before seeing of this accomplishment.

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I want to start by expressing my gratitude to my Lord Jesus Christ, who has led me and given me the health, endurance, and strength to complete all of my studies and thesis work. Everything that occurs in my life is a result of His love and forgiveness for me.

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I appreciate Manufacturing Technology and Engineering Industries Research and Development Center funding my education and all staff members for giving me accurate information.

And finally, I would like to express my respect and deepest love to my beloved families, my wife and my children for the love and support they provided me. Specially for my wife Wubalem Wolde, my children Hildana Tereda and Kidus Tereda, my mother Alemitu Dea, my sisters Aynalem Tafesse, Abezash Tafesse, Zinash Tafesse, Tesfanesh Tafesse, Helen Tafesse, Lulit Tafesse and Tenaye Tafesse and my brothers Alula Tafesse and Elsaye Tafesse.

ABSTRACT

The technological capability assessment of research and development is of utmost important to improve competitiveness. This study aims to develop a model to technological capability assessment for Research and Development and assess technological capability of Manufacturing Technology and Engineering Industries Research and Development Center. In this paper a hybrid methodology based on two approaches, the Likert scale (LS) and the analytic hierarchy process (AHP) was used. The AHP methodology was used to prioritize the set of criteria and sub criteria as a support for decision-making in the process of technological capability assessment, while the LS method was used to measure the level of consensus on particular themes. The results showed that the most relevant criteria were the technology base with 50.74%. Next were innovation (24.11%), cooperation (13.29%), technology diffusion (6.41%) and technical service (5.43%). Technology diffusion was the highest score of technological capability with 88.25% followed by technical service with 79% the average score of capability. The weakest technological capability dimension is cooperation with 35% the average score of capability followed by technology base with 43% the average score of capability and innovation with 44% the average score of capability. Conducting R&D activities is MTEIRDC's primary goal. However, there were no tangible results obtained so far. Hence, this research finding can be applied to enhance decision-making for improving technological capability of Manufacturing Technology and Engineering Industries Research and Development Center. By rationally combining the two methodologies, decision-makers can identify the aspects of a technological capability that are characterized by a weakest dimension (as revealed by the LS) and a higher priority degree (as revealed by the AHP), potentially pointing to important steps that can be taken to improve the technological capability.

Keywords: Technological capabilities, Research and Development, Technological capabilities assessment model

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LIST OF ACRONYMS

AHP- Analytical Hierarchal Process

CKD- Complete knocked down

CSIR- Council of Scientific & Industrial Research

LS - Likert scale

MTEIRDC- Manufacturing Technology and Engineering Industries Research and Development Center

SKD- Semi-knocked down

SPSS- Statistical Package for Social Sciences

R&D- Research and Development

RTO- Research and Technology Organization

TC- Technological capability

CHAPTER ONE

1. INTRODUCTION AND RESEARCH JUSTIFICATION

1.1. Background of the Study

Technological capability is a crucial resource and differentiating skill that helps firms to create firm value (Lin & Lai, 2021). To compete in the global world, businesses need to be technologically capable, especially in terms of an essential component of absorption capacity known as the ability to learn new things (Lestari & Ardianti, 2019). The company's technological capability enables it to develop goods that are superior to those of its competitors. Technological capabilities of different organizations have been assessed and proved technological capabilities of firms boost firm performance (Reichert et al., 2011; Najafi et al., 2019). Advanced technological capable businesses are better able to stand out from the competition by developing more creative products and reducing costs or increasing efficiency through process innovation (Hecklau et al., 2020b).

Centers for research and development serve as a link between academia and industry, favoring technological capability and boosting the sector's competitiveness with creative ideas (Hecklau et al., 2020a). Only technologically capable research and development centers can carry out their duties (Mortazavi Ravari et al., 2016). R&D centers should develop their own technological capabilities to improve product performance and innovation level (Zawislak et al., 2018). Due to the importance of advanced technological capability for competitiveness, the R&D center must be able to analyze and evaluate its technological capability (Hecklau et al., 2020b). The organization's ability to conduct research and development is greatly enhanced by technology capability evaluation (Paper, 2022).

Several models of technological capability assessment have appeared in the past, e.g. Rush et al. (2007), Lall, (1992). These models are created with the intention of evaluating particular organizations that are of interest to the writers but are not generally relevant to all organizations (ŠTRUKELJ & DOLINŠEK, 2011). What is required is a model that accurately satisfies the unique needs of R&D centers while also objectively and practically assessing the technological capabilities of R&D centers (Hecklau et al., 2020b). Mohammad, et al. (2010) have proposed a model for assessing technological capability in R&D centers whose primary function is the creation of new technologies. However, none of the metrics mentioned in the model are directly related to technology (or technology performance) (Hecklau et al., 2020b). The content of these numerous metrics cannot directly assess technological capability, but only provides an organization's more general (administrative, educational, financial, facilities, communications, marketing, sales, etc.) capability.

In Ethiopia there are various research and development centers established to administer development of manufacturing industries. One of the government funded research and development centers is Manufacturing Technology and Engineering Industries Research and Development Center which is responsible to support machinery and equipment industries, automotive industries and electrical and electronics industries in Ethiopia through research and development (Mtie, 2019). Manufacturing Technology & Engineering Industry Research and Development Center has been known by several names at various occasions; such as: - Engineering Design and Tool Enterprise, Basic Metals and Engineering Industry Agency, Metal Products Development Center and Metals Industry Development Institute. Engineering Design and Tool Enterprise, was founded in 1973 as a result of a contract between the Ethiopian Government and the United Nations Development Program (UNDP), with the purpose of creating various Tools and Prototypes for the National Industries (Metal Industry Development Institute, 2013). The institution began operating for seven years after being renamed "Basic Metal and Engineering Industry Agency" as recognized by the proclamation No. 47/1997. Since July 2004, the Agency has been a part of the Ministry of Trade and Industry and has focused its duties on helping industries in accordance with the government's development plan for the sector. The Metal Industry Development Institute was founded by regulation no. 182/2010 with the goal of facilitating the development and transfer of innovations related to the engineering and metals industries, as well as to help those sectors become competitive and experience rapid growth.

Manufacturing Technology and Engineering Industry Research and Development Center is established in 2021 to provide R & D services: The major activities undertaken by the center includes identification of investment opportunities & carrying out feasibility studies, technical support on implementation of investment projects, capacitate the manufacturing industry in order to improve their product quality & productivity, as well as enhancing their competitiveness(Mtie, 2019). Furthermore, the Center undertakes applied research on manufacturing technology and engineering industry, that includes machinery, equipment & spare parts; automotive, and electrical & electronics manufacturing industries. Research and development center supports manufacturing industries to increase their capacity in problem solving and is sources of solutions for problems (MIDI, 2022). Besides the non R & D services provided by the center include facilitation of: market linkage for the industries, logistics, infrastructure supply, banks loan and work permit for foreign workers.

Therefore, this paper attempts to develop a model and assess technological capability in Manufacturing Technology and Engineering industries R & D center. Companies can evaluate the strengths and weaknesses of their technology-based core capabilities and comprehend technological advancements by conducting a technological capability evaluation.

1.2. Problem Statement

Existing models for assessing technological capability are very general and do not focus on the key components of R&D center technological capability (Mohammadi et al., 2014). While some of these are general and address all facets of technology inside a company, others are more focused on that technology. Technology audit tool by Rush et al., (2007) purpose is to find out, by using the above 9 principal components, to which of the four archetypes a company that is being assessed belongs. However, the model does not explain how 9 principal components can map on to a simple model and what would be the necessary elements of such a model. Technological capability models for R&D centers by Mohammad et al. (2010) should include critical and non-essential elements that have some impact on organization, and avoid arbitrarily selecting some elements and excluding others.

There are several gaps in the Manufacturing Technology and Engineering Industries R & D Center technological capability to provide research and development services. There was no self-contained information available on the center's technological capabilities (Tadesse, 2011). The gaps in technological capabilities at the center is a direct function of the limited availability of qualified manpower in different areas of specialization, non-availability of robust databases and limited infrastructure (machines, equipment and or instruments are old and non-functional) (Team - CSIR, 2018). Present facilities and infrastructure reveals several areas where new facilities have to be created. The research council of the center do not evaluate research topics timely and approve them to move to the next level (MTEIRDC, 2023). There is no established financial system to facilitate research, product development, technology transfer and capacity building (MIDI, 2022). In general, the approach and technique being used to advance the center's technological capabilities do not adhere to scientific principles and are ineffective (Tadesse, 2011).

These problems prevent the center from providing relevant, timely and state of the art services (Team - CSIR, 2018). The research performance of the center in the year 2022/2023 was low in quantity and quality which is 45% of planned work(5 research from 11 planned) and most of the research works are at progress level and those that are finished are not really research rather complete knocked down (CKD) and semi-knocked down SKD standard development (MTEIRDC, 2023). In general, the R & D center’s capabilities are under developed to carryout productive research, product development, consulting, technological innovation and transfer and no tangible results have been achieved in recent years in R & D (MIDI, 2022).

1.3. Research Question

In order to assess technological capabilities of Manufacturing Technology and Engineering Research and Development Center and develop a new model, the following research questions were formulated:

1. What are the existing technological capability assessment models for research and development center?
2. What are Manufacturing Technology and Engineering Research and Development Center technological capabilities?

3. How to develop technological capability assessment model?
4. What key measures are needed to improve the technological capability of the center?

1.4. Objective

General objectives

The general objectives of the study were to assess technological capabilities of Manufacturing Technology and Engineering Research and Development Center and develop a new model.

Specific objectives:

- To assess existing technological capability assessment models.
- To assess the existing state of technological capability of Manufacturing Technology and Engineering Research and Development Center.
- To develop technological capability assessment model for R & D center.
- To identify key measures needed to improve the technological capability of the center.

1.5. Significance of the Study

The results of this study will be valuable for academic reference. The study developed a model important to technological capability assessment in research and development center. The findings of this study will enable the Manufacturing Technology and Engineering Industries Research and Development Center to re-evaluate its technological capability and take measures on its technological capability weaknesses. Technological capability assessment can act as both a "potential spotting system" and an "early warning system." The organization can establish appropriate strategies to strengthen its vital technological capabilities and, hopefully, increase its competitiveness on the basis of the knowledge gathered.

1.6. Scope and Limitation of the Study

The research work have the following deliverables: a model with dimensions of technologies base, innovation capabilities, technical services capabilities, technology diffusion capabilities and cooperation capability to technological capability assessment and thesis manuscript. The study made critical technological capability assessment based on the gathered data from Manufacturing Technology and Engineering Research and Development Center.

Only a questionnaire was used to acquire the data, and since expert views depend on them, they may be biased. Utilizing secondary data from Manufacturing Technology and Engineering Research and Development Center allowed researchers to get over the limitations of experts' opinion bias.

1.7. Organization of the Study

There are five chapters in the study.

Chapter 1 – Introduction and Research Justification: An overview of the research background concerns, research questions, research aims, significance of the research, scope, and research limits are provided in this part.

Chapter 2 – Literature Review: presents a related literature review of the concept of technological capability, technological capability assessment and model development. It gives particular emphasis to assess technological capability. It presents a conceptual model developed for technological capability assessment in research and development center. The new model included technologies base, innovation capabilities, technical service capability, technology diffusion capability and cooperation capability.

Chapter 3 – Research Methodology: highlights the methodological issues that underlie the study, provides further detail on the choices used for the research design, and provides details on the data collection techniques and data interpretation. The research design and methodology are provided. The sections explain the sampling strategy and ethical issues as well as the research tools that were used.

Chapter 4 - Result and Discussion: In order to facilitate decision-making during the assessment of technological capability, a set of criteria and sub-criteria were prioritized using the analytic hierarchy process (AHP). Technological capability was also assessed by using Likert scale questionnaire data using different methods like: the level of capability of technological dimensions, the existing gap in different dimensions of technological capability and average score of capability percentage.

Chapter 5- Conclusions and Recommendations: provides a summary of the research findings and recommends for the Manufacturing Technology and Engineering Industries Research and Development Center to deal with problems with technological capabilities.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This chapter firstly analyses the concepts of technology and technological capability. Secondly, technological capability assessment is discussed. Thirdly, manufacturing industries research and development center technological capability is discussed. And then, technological capability assessment models scope is discussed and is analyzed. After doing a review of the literature in these areas, a summary of the material and any gaps found within it was offered. Finaly, the conceptual model for technological capability assessment is discussed.

2.2. Concepts of Technological Capability Assessment

This section explains important concepts of technology, as well as technological capability which underpin these philosophies.

2.2.1.Technology

Defining technology is not an easy term. In fact, there is no single clear, compelling, and widely accepted definition or concept of what technology really is. Different definitions of technology exist.

Technology is the methodical application of structured knowledge, such as that found in science, to practical problems (Abdul & Abdullah, 2014). Technology is the set of methods, processes, tools, equipment and machines, skills and knowledge used to produce goods or provide services (Hadi, 2019). The following technology can be divided into four basic parts in accordance with the definitions given above:

1. Tools and equipment
2. Human capability
3. Knowledge of information and technology
4. Organize and oversee

2.2.2. Technological Capability

Technological capability describes the abilities, expertise, processes, and resources that a business needs to create new goods and/or services (Zawislak et al., 2018). Technological capability refers to the ability (competence) to use technology (and the knowledge and skills required to use it properly) in ways that help achieve goals effectively and successfully (ŠTRUKELJ & DOLINŠEK, 2011). Technology capabilities include not only physical equipment, manuals, blueprints, employee education and personal skills, but also the ability to function as an organization (Putranto et al., 2003).

Therefore, technological capability could be conceptualized as a capacity of an organization to purposefully use technology as one of its resources.

2.3. Technological Capability Assessment

Technology capability assessment is the process of measuring an organization's current performance and level of technology capabilities, identifying strengths and areas for improvement, and comparing them to competitors' technology capabilities, ideal levels, and technology gaps (Putranto et al., 2003).

Eren & Eyitmiş (2017) identified R&D companies in technology development zones that have their technological skills. The data collected from a few businesses in Technology Development Zones was used in the study to define the antecedents of technological capabilities.

Tsai (2004) investigated the effect of technological capabilities on business success with reference to Taiwan's electronics sector. He conducted a longitudinal study and obtained an econometric dataset. Applying the model, he concluded that a company's technological capabilities improve its performance.

According to Gewe et al., (2016) government-backed or initiated outsourcing networks benefit small and medium enterprises (SMEs) in developing technological capabilities. Among the talents small businesses can develop are technical learning, acquiring new technology, market access, and process innovation.

TADESSE, (2011) surveyed Ethiopian metal manufacturing and engineering industries, presented the scenarios for the technological capability of the industry. The sector is currently in need of improvement or renovation, and development strategies are provided.

These theoretical & empirical researches have not considered the need of technological capability assessment in R & D developments.

2.4. Manufacturing Industries Research and Development Center Technological Capability

The goal of research and development (R&D) is to add to the body of information, including understanding about people, cultures, and civilizations, and to create new applications for the knowledge already in existence (OECD, 2015). R&D is described as the actions a corporation engages in to advance its understanding of science, engineering, and/or related fields (Hecklau et al., 2020a). Research and development (R&D) companies work to create technological solutions that turn cutting-edge goods and services into the findings of science and research. Only when technology capabilities and resources are exploited effectively and economically to create competitive advantages can this be accomplished.

Range of Activities performed by Research and Development (R&D) include: basic research; applied research; experimental development; design and applications engineering; technical services (e.g. prototyping or pilot batch manufacturing of new products, use of advance facilities, etc.); standards and certification (e.g. training, provision of technical advice); and diffusion (e.g. consultancy, training, maintaining information services, administering government programmes, etc.) (Arnold et al., 1998).

The three levels of manufacturing industries technological capabilities are as follows: basic, intermediate, and advanced (Khandelwal, 2005). Basic technological capabilities include the ability to operate and maintain a new production facility based on imported technology. Intermediate technological capabilities include the capability to replicate and adapt an imported plant's design elsewhere in the country or abroad. Advanced technological capabilities include the capability to undertake new designs and to develop new production systems and components.

2.5. Technological Capability Assessment Model

The various models developed and used internally to assess technological capability require two basic characteristics. It must first be clear and simple to understand and must also produce results quickly enough to be considered acceptable (Khamseh & Mohagheghi, 2013). Models for assessment of the technological capability of organizations are: technology management process assessment by Phaal et al. (2001), technology audit model by Rush et al. (2007), model for assessing technological capability in R&D centers by Mohammad et al. (2010) and evaluation of the technological maturity of applied red organizations by Hecklau et al (2022).

2.5.1. The Technology Management Process Assessment

The Technology Management Process Assessment model developed by Phaal et al., (2001) in three stages: strategic overview, process overview and process investigation that are carried out in employee workshops. The technology management process is shown in the figure 2.1:

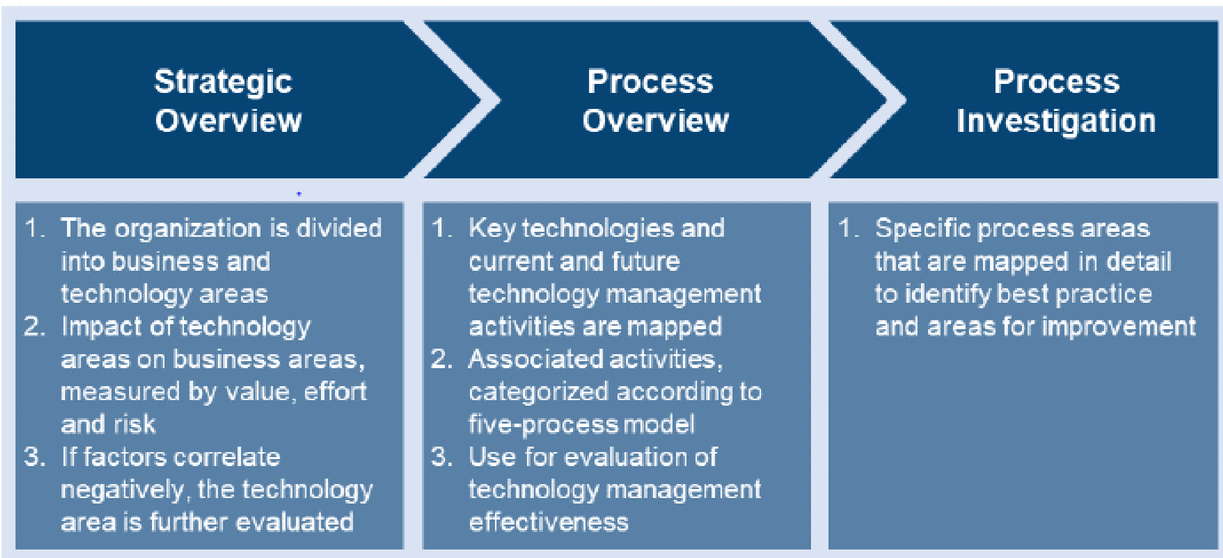

Figure 2-1 Technology Management Process

Soure: (Hecklau et al., 2020b)

Technical areas and commercial units are separated inside the company in the first phase, **strategic overview**. The value, effort, and danger posed by the unit are then considered in assigning grades to each technology area on a scale of high, medium, low, and unimportant. These variables naturally have a positive correlation(Hecklau et al., 2020b). If this doesn't work, the second stage, called "**Process Overview**," evaluates the technical areas. Key enabling technologies for the technology categories identified in Phase 1 will be associated with ongoing and future technology management initiatives during this phase. For each KET, workshop participants will be required to enumerate significant events that have occurred throughout time (for example, the last five years). Relevant activities are categorized using Gregory's Five Process Models (Technology Identification, Selection, Acquisition, Use, and Protection) to assess the effectiveness of technology controls based on inputs, processes, and outputs. Next, score these on a scale of 1 to 5 where 1 is "strongly agree" and 5 is "strongly disagree". The third stage, Process Investigation, maps out particular process areas in depth to pinpoint best practices and potential improvement areas.

Technology management process assessment by Phaal et al. (2001) is entirely qualitative and ignores technology substance and hard considerations. This model is a method that may be used to evaluate technology management procedures in diverse firms because it is reasonably broad. It comprises of a number of assisted workshops built upon thorough workbooks with instructions and best practices. However, it serves as a self-assessment tool of limited value to objectively assess technology management within an organization (Hecklau et al., 2020b). In order to build essential technology, the function, merits and demerits of technology management are evaluated, not the hardware aspect or technical content. As a result, it can only be used indiscriminately to evaluate the technical prowess of R&D organizations.

2.5.2. Technology Audit Model

In 2007, Rush et al. presented a technology assessment model based on an effort to connect knowledge of important technological innovation skills to the stage of technological capability development that enables businesses to choose and apply technology to build a competitive advantage. The Technological Capability Audit Tool uses nine main components: “Awareness”, “Searching”, “Core Competencies”, “Strategy”, “Assessment”, “Acquisition”, “Implementation, Absorption and Operation”, “Learning”, “Exploiting external linkages and incentives” that are self-explaining to build a survey to assess an organizations technological capability.

Figure 2-2 Categorization of technological capabilities

Source: (Torkashvand, 2014)

Awareness refers how technology affects competitiveness and senior management's capacity to understand the risks of "stopping" in today's competitive world. **Searching** is the capacity to scan or keep an eye on external technological events and trends that can have an impact on your organization or open up prospects for expansion or competition. **Building of core competencies** refers to a company's ability to identify its unique technological capabilities and develop a competitive advantage in particular fields. **Development of a technology strategy** is the process of setting and communicating your vision, goals and priorities. Even firms with the most resources are limited in what they can accomplish in terms of technology. Choosing which technology tasks to carry out internally and which to outsource to partners is thus part of the strategic challenge. **Assessment of technological options** by contrasting all feasible possibilities that can be realized through benchmarking, feasibility studies, etc., and choosing the best option based on that comparison. **Acquisition of the technology** when a choice is made on a new technology, the business commits resources to utilizing it, either by producing it internally through research and development (R&D) or by purchasing it through joint ventures; technology licensing, etc., is required. **Implementation, absorption and operation of the technology within the firm** a business must deploy new technology once it has acquired or developed it for use within the company. This covers the many phases of final implementation and market launch, including learning how to use new production processes and methods, as well as new products and services introduced within a business. **Learning** includes looking back and examining internal technical initiatives and processes to learn from triumphs and errors. It is a crucial component of developing technological aptitude. **Exploiting external linkages and incentives** for technology and related services, businesses must turn to outside vendors (consulting firms, government research centers, colleges, etc.).

4 different statues are used to evaluate the condition of a main component: “Unaware or passive”, “Reactive”, “Strategic”, and “Creative”. These four types allow each major component to be assigned a specific number of points. These four types allow you to assign a specific number of points to each principal component. Although the evaluation results provide numerical results, the model leads to highly subjective evaluations.

Hence, technology audit tool, proposed by Rush et al. (2007), is aimed to give a way for policy makers to customize support based on the firm's level of competence. This approach only applies to businesses that compete in a market economy and whose rivalry is driven by technological advancement. This model does not apply to other organizations and is not a general model for assessing technical competence. However, this measure is only one of many required for such a goal (policy success). Although the evaluation results provide numerical results, the model leads to highly subjective evaluations.

2.5.3. Model for Assessing Technological Capability for R&D Centers

Mohammad et al. (2010) have proposed a model for assessing technological capability for R&D centers whose primary job is creating technology. In a proposed model for technology capability assessment in R&D centers, capability is assessed both at macro and micro level.

The following Figure summarizes the Mohammad et al. (2010) model for the assessment of the technological capability in R&D organizations.

Figure 2-3 Model for technology capability assessment in R & D Center

Source: (Hecklau et al., 2020b)

Indicators used at the macro level assess problems common to all innovative organizations. These metrics are evaluated across the organization and include: Place of Innovation in Organizations, Importance of Knowledge Management and Knowledge Acquisition, Place of Innovation in Strategy Development, Learning, Teamwork and Training. The technical performance of R&D organizations is evaluated at a micro level. This is based on the separate evaluation of each of R&D centers' main activities that are divided into 4 main groups, and based on these groups, 4 types of capabilities can be defined for assessment: capability of internal development of technologies, capability of technology development via cooperative R&D, capability of performing basic researches, and capability of presenting consultation services to industry. Mohammad, et al. (2010) has identified numerous indicators to be appropriate for technology capability assessment in R&D centers. These indicators are divided into 6 groups: human resource indicators, equipment's, knowledge management and communication indicators, management indicators, marketing and sales indicators, achievements indicators. Technological capability of an R&D organization is assessed only at the micro level. However, it is somewhat contradictory to propose a technology assessment model in which technical competence is evaluated only in some areas and not in others. Also, the model fails to explain how the macro level relates to the micro level and how the macro level results relate to the micro level results.

2.5.4. Evaluation of the Technological Maturity of Applied R&D Organizations

Three main dimensions form the basis for the assessment. These dimensions target the applied R&D organizations technology base, products and services, and collaborations (Hecklau et al., 2022). The technological base of the RTO serves as the "input-dimension" technologies and competencies that are really employed to carry out R&D projects and are available are assessed. The output-dimension, which is called products & services, concentrates on the outcomes of the completed R&D initiatives. This dimension analyzes and evaluates technologies that are created as products or technological services. In the third dimension, the cooperation, partnership-based technical synergies are assessed. Figure 2.4 describes dimensions of technology audit.

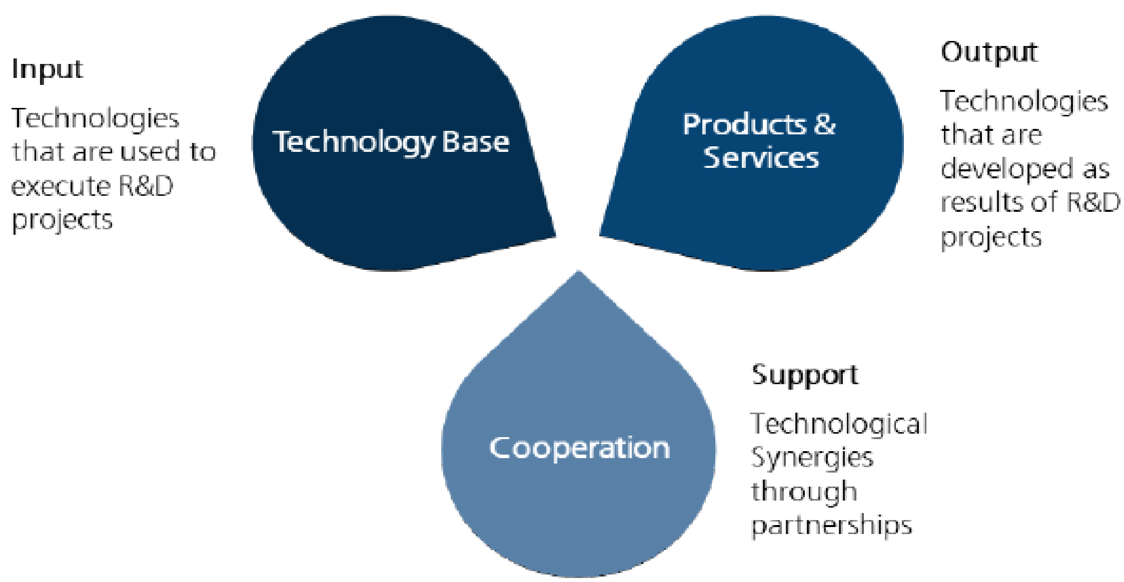

Figure 2-4 Dimensions of technology audit

Source: (Hecklau et al., 2022)

- **Technology Base**

  Technology base focuses on the technology and RTO competencies that are utilized to carry out R&D initiatives. It is possible to recognize and operationalize three key components.

  - Core competences-
  - Technologies, equipment and infrastructure and

- Future technology developments.

- **Products & Services**

  In the area of products and services, mainly focus on the results of research and development. The following points are evaluated: carry out research and development projects and transform cutting-edge technologies into products and services, as well as potential new technological solutions, products and services.

- **Cooperation**

  On the cooperation dimension, in order to gain access to partners' complementary research competencies, which are required for project execution, the level of integration of the RTO within the regional, national, or even international innovation ecosystem is examined and assessed.

Technological maturity model is consists of different levels for the assessment of an RTO within the scope of the technology audit, where each of the assessment dimensions and items will be evaluated according to this model.

The generic technological maturity model is visualized in the following figure.

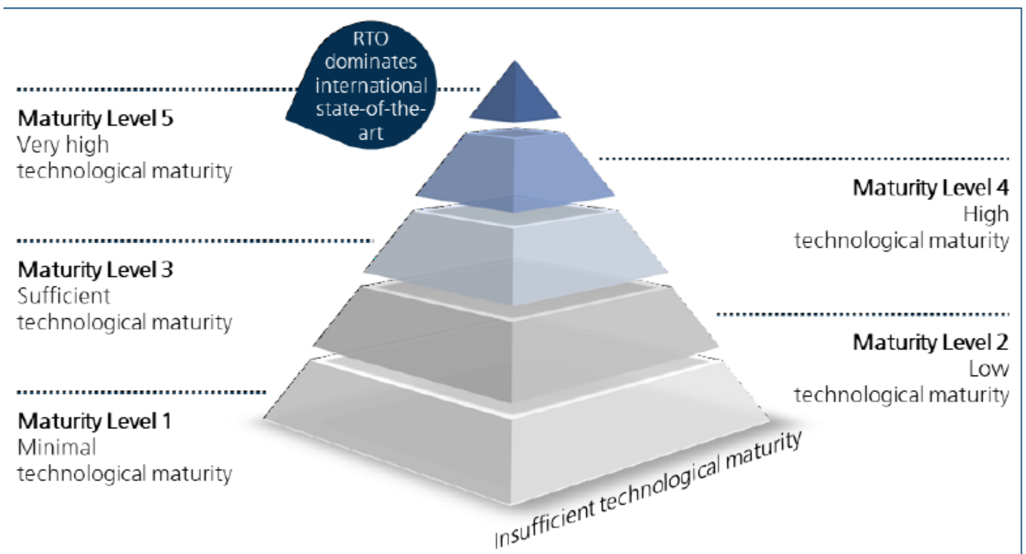

Figure 2-5 Technology maturity model

Source: (Hecklau et al., 2022)

The RTO is deemed operational with all the required technologies, equipment, research competencies, and strategic technological partnerships to carry out R&D projects in its defined service areas if it reaches technological maturity level 3, which signifies that the technological maturity is sufficient. When an RTO attains a technological maturity level of 4 or higher, it is considered to be extraordinarily mature and capable of executing challenging R&D projects and creating cutting-edge technical innovations.

2.5.5. Firm-Level Technological Capabilities

Technological capabilities are categorized into three functional groups: investment capabilities, production capabilities, and linkage capabilities (Lall, 1992).

Investment capabilities: the abilities needed to plan, gather technologies, design, build, outfit, staff, and run a new facility (or expansion). These include the project's capital costs, the scale that is appropriate, the product mix, the technology and equipment used, and the operating company's technical know-how (which affects the facility's following efficient operation).

Production capabilities: The most difficult skills are those in research, design, and innovation. Basic skills include quality control, operations, and maintenance. Advanced skills include adapting, enhancing, or "extending" equipment. These cover industrial technology monitoring and control practices in addition to process and product technology. Your ability to use and advance current technology as well as how well your internal attempts are made to include technology that has been purchased or stolen from others are both impacted by the skills you need.

Linkage capabilities: are required to send and receive data, expertise, and technology to and from subcontractors, consultants, service providers, and technical agencies as well as suppliers of parts and raw materials. Such connections have an impact on enterprises' efficiency (enabling them to specialize more), as well as the spread of technology across the economy and the fortification of the industrial structure, both of which are crucial for development. Additional market links are crucial to boosting productivity, according to research on industrialized nations.

Table 2-1 Illustrative matrix of functional

FUNCTIONAL									
			Investment		**Production**			**Linkages Within Economy**
			Pre Investment	**Project Execution**	**Process Engineering**	**Product Engineering**	**Industrial Engineering**	
Decree of Complexity	Basic	Simple, Routine (Experience Based)	Prefeasibility and feasibility studies, site selection, scheduling of investment	Civil construction, ancillary services, equipment erection, Commissioning	Debugging, balancing, quality control preventive maintenance,	Assimilation of product design, minor adaptation to market needs	Work flow, scheduling, time-motion studies. Inventory control	Local procurement of goods and services, information exchange with suppliers
	Intermit	Adaptive Duplicative (Search based)	Search for technology source. Negotiation of contracts bargaining suitable terms. for systems	Equipment procurement, detailed engineering, training and recruitment of skilled personnel	Equipment stretching, process adaptation and cost saving, licensing new technology	Product quality improvement, licensing and assimilating new imported product technology	Monitoring productivity, improved coordination	Technology transfer of local suppliers, coordinated design, S&T links

FUNCTIONAL								
			Investment		**Production**			**Linkages Within Economy**
			Pre Investment	**Project Execution**	**Process Engineering**	**Product Engineering**	**Industrial Engineering**	
	Advanced	Innovative Risky (Research based)		Basic process design. Equipment design and supply	In-house process Innovation, basic research	In-house product innovation, basic research		Turnkey capability, cooperative R&D, licensing own technology to other

Source: (Lall, 1992)

This firm-level technological capability by Lall, (1992) mainly focus on the application in production companies.

Therefore, it is not feasible to use these models to evaluate the technological capabilities of R&D facilities in an unreflected manner.

2.6. Literature Summery

This chapter presented a review of technological capability assessment literatures published over the last two decades. It assesses concepts of technology, as well as technological capability and research and development concepts. Moreover, it focuses on technological capability assessment. It also aimed to assess the contribution of different researches on the various model of technological capability assessment.

To sum all up, the literature review revealed many useful information for assessing technological capabilities in the organization. The following table summarized indicators used for assessing technological capabilities.

Table 2-2 Summarized indicators

Indicators	**Models**				
	Technology Management Process Assessment model	**Technology audit model**	**Model technological capability in red centers**	**Technology maturity model**	**Firm-Level Technological Capabilities**
Process overview	✓				
Process investigation	✓				
Awareness		√			
Searching out triggers for change		√			
Building of core competencies		√		√	
Development from these of a technology strategy	√	√	√	√	
The exploration and assessment of the range of technological options available		√			
Acquisition of the technology		√	√		
Implementation, absorption and operation of the technology within the firm		√			
Learning		√	√		
Exploiting external linkages and incentives		√	√	√	√
The position of innovation in the organization			√		
Team working			√		
Presenting consultation services to industry			√		
Technology base				√	

Indicators	Models				
	Technology Management Process Assessment model	Technology audit model	Model technological capability in red centers	Technology maturity model	Firm-Level Technological Capabilities
Investment capabilities,					✓
Production capabilities,					✓

Source: Author

2.7. Literature Gap

The review had confirmed what was previously mentioned that the literature shows that there are some insufficiencies and critical elements in these models. All the models were designed for application in specific organizations and not for general application. It may be said that each model adds to the conversation on how to evaluate a research and development center's technological capability, but no analyzed models fully meet technological dimensions like technical service capability and technology diffusion capability. Technology management process assessment does not evaluate hard aspects or technological substance, but rather the functions and advantages and disadvantages of technology management. Therefore, it can only be used informally to evaluate technological competency at R&D facilities. Technology audit tool, proposed by Rush et al. (2007), applies only to companies that compete in a market economy and does not apply to R & D organizations. Technology capability assessment model in R&D centers by Mohammad et al. (2010) have identified numerous indicators but does not include all technology dimensions like technical service, technology diffusion. Evaluation of the Technological Maturity of Applied R&D Organizations collaborations by Hecklau et al., (2022) does not include all technology dimensions like technical service, technology diffusion. Hence, to create a new model, a holistic approach is required.

2.8. Developing Conceptual Model

There have been attempts to develop a model to assess technological capabilities in the former studies (Phaal et al., 2001; Hecklau et al., 2022; Mohammad et al., 2010; Lall, 1992; Rush et al., 2007). However, the purposes of these models are different and as a result of this fact, the models deployed are covering different dimensions. In this section the researcher propose a model for technological capability assessment in research and development center. So, this study utilized a new methodology to develop a conceptual model to assess technological capabilities by adopting the former models. In this model a holistic approach to technological capability assessment in organization is taken. Based on different approaches reviewed in the previous section, the researcher shaped different dimension of technological capability assessment model. The new model included technology base, innovation, technical services, technology diffusion and cooperation. The conceptual model created to evaluate technological capability in the context of the study's literature review.

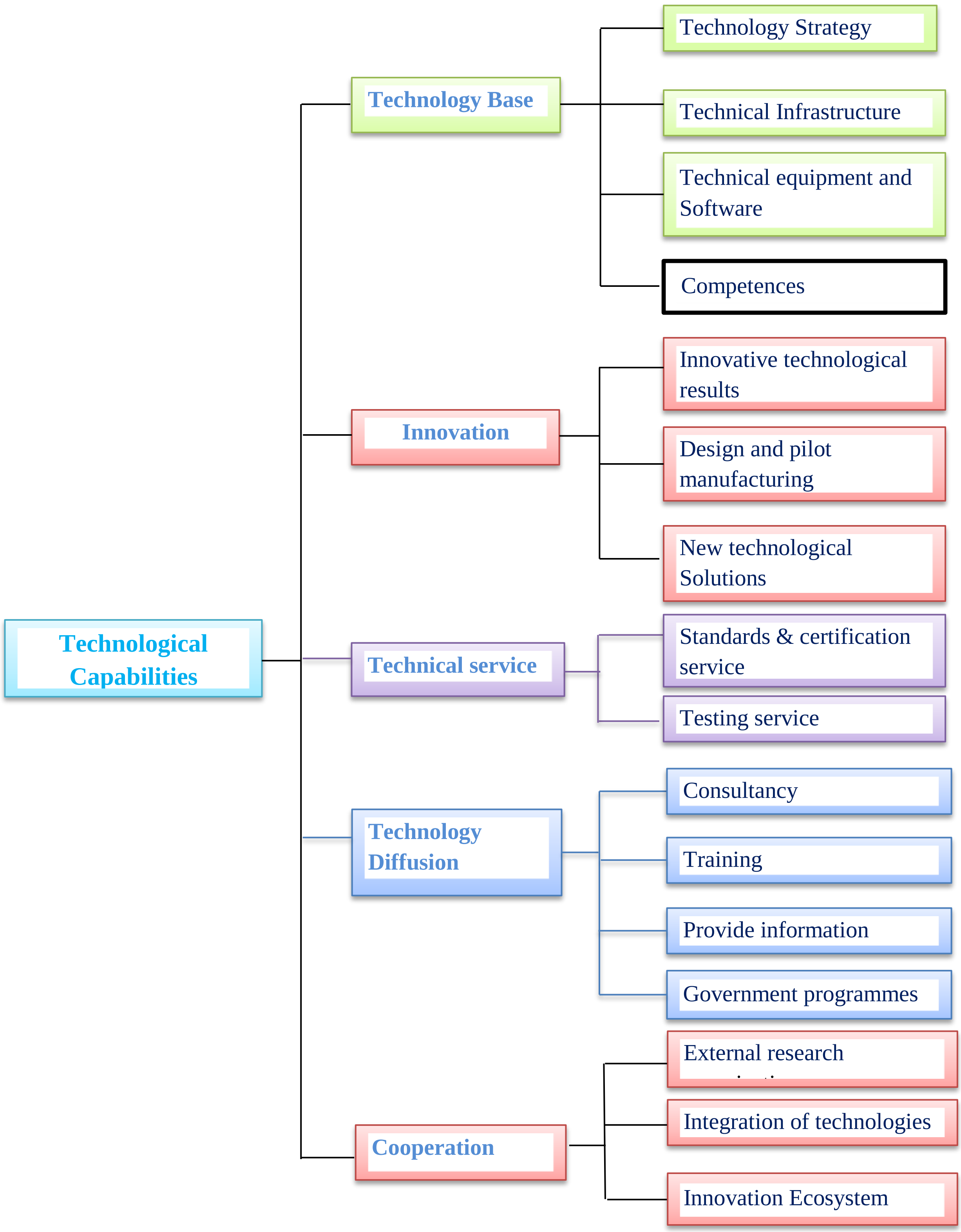

Figure 2-6 Developed conceptual model to assess technological capability of R & D center

Source: Author's based on literature survey

2.8.1. Indicators to Asses Technology Capability of R & D Center

a) Indicators of Technology Base

Table 2.3 shows indicators of technology base

Table 2-3 Indicators of Technology Base

Indicators	Assessment items
Technology Strategy	Awareness of new usable technologies
	Effective and efficient resource planning
	Technology road mapping (external)
Technical Infrastructure	Building(s)
	Maintenance of Infrastructure
Technical equipment and Software	General and Specific Equipment/ Software
	Maintenance of Equipment / Software
Competences	Core Competences
	Qualification of Staff
	Competence Development

Source: (Hecklau et al., 2022)

The technologies and skills that are actually used to carry out R&D projects make up an R&D center's technology base.

b) Indicators of innovation capability

Table 2.4 below shows indicators innovation capabilities

Table 2-4 Indicators of innovation capability

Indicators	Assessment items
Innovative Technological Results	High-Quality Research Work (basic, applied and Experimental development)
	Technology Protection / IP
Design and pilot manufacturing	Design and applications engineering
	Prototyping or pilot batch manufacturing of new products

Indicators	Assessment items
New Technological Solutions as Products	Technology Road mapping (internal)

Source: (Hecklau et al., 2022)

The main focus of the innovation capabilities dimension is on the outcomes of research and development as well as the invention of novel solutions.

c) Indicators of technical service capability

Table 2.5 indicators of technical service capabilities

Table 2-5 Indicators of technical service capability

Indicators	Assessment items
Technical services	Testing
	Standards and certification

Source: (Arnold et al., 1998)

Technical service capabilities are employed to increase the client base and produce more income.

d) Indicators of technology diffusion capability

Table 2.6 shows indicators of technology diffusion capability

Table 2-6 Indicators of technology diffusion capability

Indicators	Assessment items
Technology diffusion	Consultancy
	Training
	Maintaining information services
	Administering government programmes

Source: (Arnold et al., 1998)

Technologies created through inventive effort are expanded using technology diffusion capabilities.

e) Indicators of cooperation capability

Table 2.7 shows indicators of cooperation capability

Table 2-7 Indicators of cooperation capability

Indicators	Assessment items
Cooperation with external research organizations	Universities
	Research and Development Centers
Integration & usage of technologies from externals	Integration & Usage of Technologies from Service Providers
	Integration & Usage of Technologies from Customers
Cooperation with Innovation Ecosystem	Start-Ups
	Incubators and Accelerators

Source: (Hecklau et al., 2022)

To determine if they are performing well or poorly in the sector, businesses must benchmark their processes against other businesses. They must establish connections and work together with business partners to accomplish this. Activities that were technologically successful were highly specialized and done in close collaboration with businesses. They were frequently the outcome of lengthy partnerships with task-driven businesses.

Using the aforementioned indicators, we can develop a list of questions to pose to companies to help assess their technological capacity. For the purpose of assessment, the researcher has created questionnaires (appendix - 1 & 2) utilizing a five-step Likert scale and the analytical hierarchical process (AHP).

2.8.2. Technological Capability Levels of R & D Centers

Based on the technology capability assessment model for research and development center, questionnaire is developed in appendix 1. From the questionnaire response scores you can now calculate your company's current overall technology capability level.

Your overall organizational capability level is indicated in the table 2.8 by adding up your total score (the maximum score is 135).

Table 2-8 Technological capability level of R & D center

Capability Level	Total Possible Score	Overall Audit Result
Minimum Level	27	In all key technological areas, these companies are underdeveloped and unprepared. Huge advancement program is desperately required.
Low Level	28-54	Due to a lack of internal resources, these companies need stronger technological skills to meet their goals.
Medium Level	55-81	These companies recognize the need to advance technology capabilities to meet development goals, but due to insufficient internal resources, they can only react to external forces.
High Level	82-108	Strong internal capabilities are present at these companies. Although the company lags behind the global technology frontier in some sectors, it has numerous significant assets.
Very High Level	109-135	These companies are able to shape the global technology frontier because they have a fully established set of technological skills.

Source: Author's based on litreture review

Figure 2.6 shows technological capability level based on Table 2.8 score

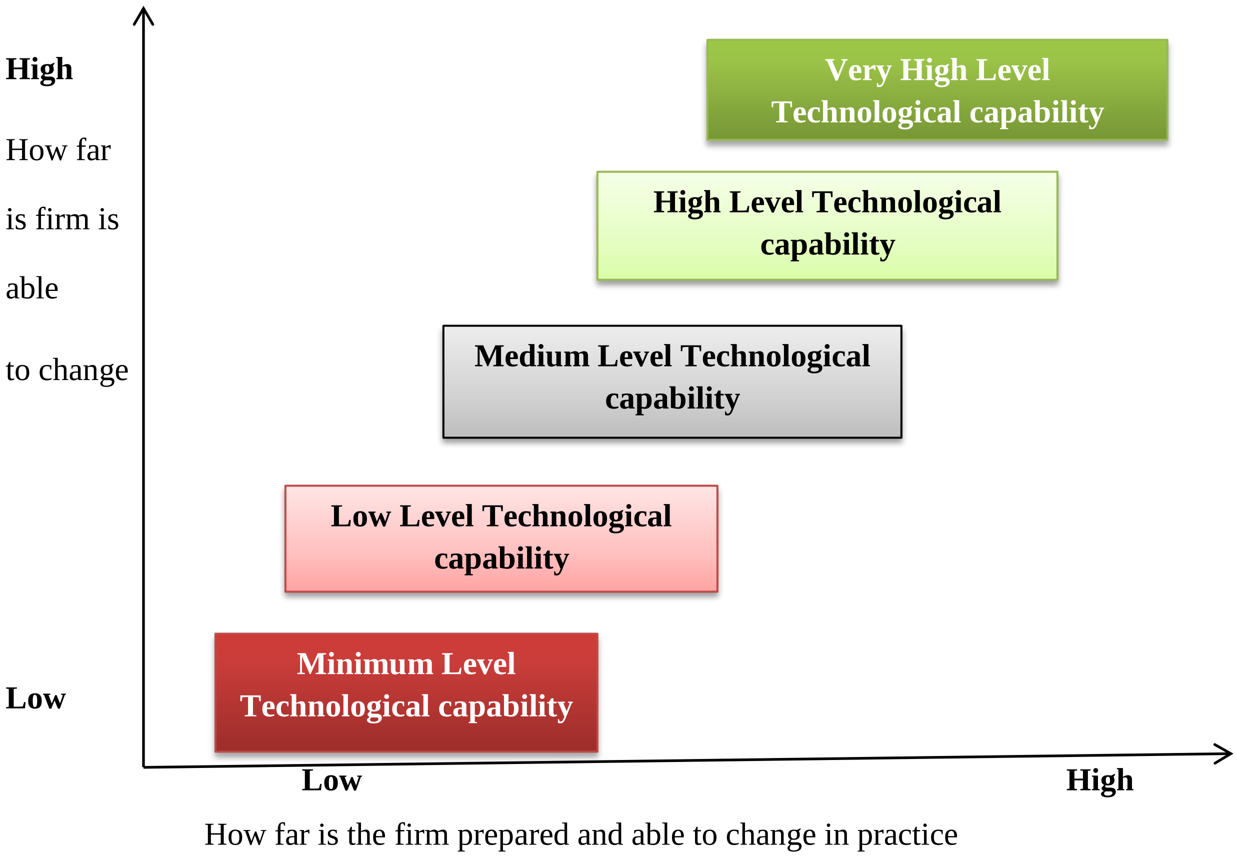

Figure 2-7 Technological capability level of R & D center

Source: Drawn by author based on literature review

According to the model and based on the categories in Table 2.8, R & D centers are divided to five types in terms of the technological capabilities. A technological capability level consists of 5 different levels, starting with level 1 – minimal technological capability – and ending with the highest level 5 – very high technological capability.

Minimum Level Technological capability: the first type of R & D center is does not have core technological capabilities.

Low Level Technological capability: These companies recognize that greater technological capability is needed to achieve development goals, but that this is due to insufficient internal resources (lack of essential skills and personal experience).

Medium Level Technological capability: These companies recognize the need for improved technology capabilities to achieve development goals, but due to insufficient internal capabilities, they can only react to external pressures and are unable to take advantage of the opportunities.

High Level Technological capability: These businesses have a keen sense of strategy, a strong capacity for project completion, and a solid understanding of how to increase their technological skills. The company is regarded as operational with all the required tools, expertise, and strategic technical alliances to carry out R&D projects in its specified service areas.

Very High Level Technological capability: If an R & D center reaches a very high level technological capability, it means it is able to execute complex R&D projects and develop very innovative technological solutions.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Introduction

This chapter elaborates on the research design choices, examines the methodological issues that underlie the study, and describes the data collection procedures and data analysis. A discussion of the research philosophy that guided the study is presented in the chapter's opening paragraphs. The research approach and methodologies used are then described. The following parts go through the research tools that were used as well as the sample strategy and ethical issues.

3.2. Description of the Study Area

The research focused on Manufacturing Technology and Engineering Industries Research and Development Center in Ethiopia. Manufacturing Technology and Engineering Industries Research and Development Center is under Manufacturing Industries Development Institute. Manufacturing Industries Development Institute is under Ministry of Industry in Ethiopia.

The main objective of the Manufacturing Technology and Engineering Industries Research and Development center is to conduct research in technology and engineering industry and turn it into prototype products and create investment arrangement by private sector for mass production. The Manufacturing Technology and Engineering Industry Research and Development Center is divided as core teams and the support teams. Core teams are those that are engaged in research and development activity whereas the support team provides support for the core activities.

Hence the study focused in core team where there are 50 professional engineers where the survey focused on these engineers.

3.3. Research Design

The goal of the research design is to give the study an adequate structure. It is a comprehensive strategy utilized to direct the study based on reaching its goals. Making a selection on the research approach is a crucial step in the study design process.

The research type used is exploratory research. Exploratory research provides significant insight into a given situation. The researcher explored differed models available to assess technological capability and developed a model suitable to assess technological capability of research and development centers. Fig 3.1 shows the framework of the research method.

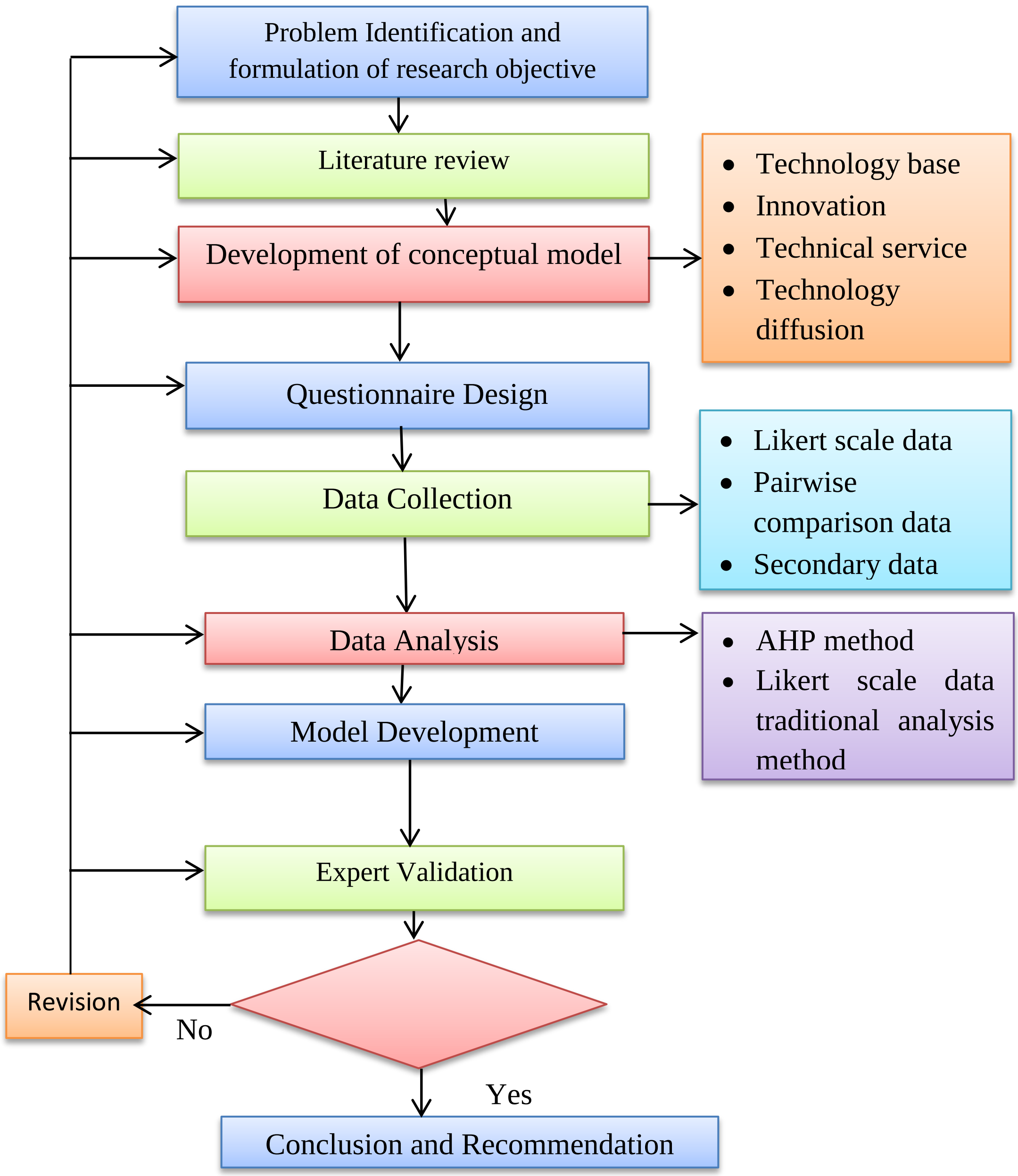

Figure 3-1 Framework of the research method
Source: Author's

3.4. Research Methodology

The methods followed to achieve the desired objective are discussed in the following sub-sections.

Literature review: A thorough review of the pertinent literature was done in order to comprehend the many theoretical and practical components of the study. For this, relevant literature from journals and books was consulted, along with other study papers, and it was noted which models other researchers used to evaluate their technological capabilities. For literature search standard sources were used e.g., theses, online resources.

Secondary data sources: To get the secondary data relevant documents such as reports, published and unpublished documents are reviewed.

Case study

The usage of questionnaires was adopted because they offer a platform for asking the same set of questions of every respondent. This allowed for an effective method of gathering data before the necessary quantitative analysis. A chosen group of experts from the Manufacturing Technology and Engineering Industries Research and Development Center were picked in order to conduct the study while keeping in mind its goals. Then, tools were pre-tested to determine the validity and reliability of the tool.

Model development: many models are derived, tested and built upon until a model fitting the desired is built. Most standard model was created using the literature review and AHP analysis done.

Validation of the model: The specialists were consulted to validate the proposed model. A few well-known experts and professionals in the relevant fields were contacted through email for this reason and asked to remark on the suggested model. Received observations were examined qualitatively and ideographically.

3.5. Study Population and Sampling Design

According to Manufacturing Technology and Engineering Industry Research and Development Center Human Resource department there are about 50 professional engineers. All these 50 professional engineers are the study population. As the whole population is small, the researcher took the 50 professional engineers as the sample size.

3.6. Pre Testing

Based on the signs discovered from the literature and desk research, a draft questionnaire was created. To ensure that the questionnaire was thorough and simple to comprehend and reply to, a draft was forwarded to specialists for review. Additionally, respondents were requested to add relevant indicators that had not yet been included in the original questionnaire and to eliminate indicators that were irrelevant to the dimension. Respondents thought that several metrics were not adequately explained, and that some words were either simple or not fully comprehended, according to the questionnaires that were returned. The researcher modified several indicators based on their feedback and produced the final survey.

Pre testing is essential in that it offers an opportunity of detecting any probable weaknesses in the research instrument. A pretest was conducted among 5 employees working with Manufacturing Technology and Engineering Industries Research and Development Center who were selected randomly. The aforementioned respondents were excluded from the final survey in order to preserve the validity of the results. The data collected in the pretest were analyzed with the object of determining both reliability and validity of the research questionnaire used in the final study.

3.7. Validity of the Research Instrument

Validity is the level of justification for test result interpretations to be considered. To valid the data and model the questionnaire and developed model had been sent to my adviser and also to some of the researchers and their notes were taken into consideration to improve some of the idea.

3.8. Reliability of the Research Instrument

Reliability is asserted to be a measurement of how reliably an instrument can gather comparable data when used with various populations and/or at various times.   Measures that are given to the same people at various periods or that utilize the same standard are evaluated for stability using reliability estimates.

3.9. Data Analysis and Presentation

In this research the conceptual model and its dimensions and indicators have been determined and customized with regard to conditions of MTEIRDC. Two questionnaires were developed to collect data. In the first questionnaire, by selecting one of the five options on the Likert scale—strongly agree, agree, uncertain, disagree, and strongly disagree—respondents were asked to indicate how much they agreed or disagreed with each item. The second questionnaire related to the AHP and consisted of comparisons. The questionnaires were divided into two parts. The first part enquired about basic information concerning the respondent, such as age, sex, education and work experience. The second part of the questionnaire asked about the importance of each indicator.

After population-based data were gathered, an office-level editing technique was utilized to check and repair any problems. Before analysis, the raw data were modified and coded. Two different methods were implemented to analyses the data acquired by the questionnaire, the Likert Scale approach and the analytical hierarchy process (AHP) using Spice logic Analytical Hierarchy Process software.

The Likert scale is a psychometric scale employed to study the degree of user satisfaction by measuring opinions. The collected data were processed and analyzed using the Statistical Package for Social Sciences (SPSS) version 23 software and Excel. Narratives and perspective interpretations were used to analyze quantitative data that had been summarized. The AHP is a multiple-criteria decision-making technique that assigns a weight to each evaluation criterion based on how the decision-maker evaluates the criteria in pairs (Saaty, 2008). AHP is superior to other multi-criteria procedures like Fuzzy AHP, DMATL etc. when expert opinions from many sources play a significant role in the decision-making process since it is made to function with both tangible and intangible criteria.

The steps followed in AHP analysis is explained in the parts that follow.

1) **Step 1: The objective's identification**

Identification of the issue and the job at hand's technological capability assessment goal constitute the first step of the AHP.

2) Step 2: Choosing the evaluation criteria

The problem of the research area and the opinions of decision-makers and experts are taken into consideration when choosing the aspects (criteria and sub criteria) most frequently used in research and development technological capability assessments prior to beginning the AHP procedures.

3) Step 3: Construction of the hierarchical structure

There are numerous levels of assessment involved in building the hierarchical structure. To simplify the evaluation, the procedure separated the complex decision-making into a simple hierarchical structure of all its components, each of which was divided into layers that are individually examined.

4) Step 4: The creation of the decision matrices

After the hierarchical structure has been built, the next step is to make decision matrices for each element at each level. The application of expertise and judgment by the experts may help in locating the decision matrices for each level of the hierarchical structure. In order to generate and rank the relative and total weights, the decision matrices were created by comparing each element's preference to every other element. The comparison between the elements i and j produced the words aij (wi/wj), which were then organized into a matrix A of paired comparisons. Equation 1 shows that the aji position of A is filled with the opposite values of the comparisons. The Saaty scale (Table 3.1) served as the foundation for these experts' conclusions.

$$A = \begin{pmatrix} 1 & a_{12} & \ldots\ldots\ldots & a_{1n} \\ 1/a12 & 1 & \ldots\ldots\ldots & a2n \\ . & . & & . \\ 1/a1n & 1/a2n & \ldots\ldots & 1 \end{pmatrix} \quad (1)$$

Pairwise comparisons between elements i and j for elements i, j are made in the decision matrix A using the formula aij.

∈ {1, 2,. . ., n} and aii 5 1 et aij 5 1/aji where n denotes how many of each element there are in the decision matrix.

The scale shown in Table 3.1 was proposed by Saaty (2008).

Table 3-1 Pairwise comparison

Numerical rating	**Definition**
1	i is equally important to j
3	i is slightly more important than j
5	i is strongly more important than j
7	i is very strongly more important than j
9	i is extremely more important than j
2,4,6,8	Intermediate
Reciprocals	When compared to activity i, j has the reciprocal value if activity i has one of the aforementioned values allocated to it.

Source: (Saaty, 2008)

5) **Step 5: Calculating each element's priority vector**

Priority vectors (relative weights) are computed in this stage for each of the decision hierarchy's components (criteria and indicators). The comparison matrix is used to evaluate the relative weights (following professional opinion). The sum of all weights must equal 1.00, which must be verified next. It is necessary to take the following actions in order to determine the relative weights:

- Determine the sum of each column in the matrix "A"
- The normalized matrix "B" is obtained by dividing each column's sum by the elements of matrix "A".
- The average of each row in matrix "B" should be calculated.

6) **Step 5: Look at the consistency ratio (CR) for each element.**

In order to apply the AHP approach, the CR calculation is a crucial step. This phase is crucial for determining whether the decision matrix is consistent or inconsistent. The CR should be equal to or lower than 10%, according to Saaty (Saaty, 2008). By contrasting a consistency index (CI) with a random index (RI), the CR is determined. The actions listed below must be taken in order to verify the consistency of the decision matrix:

- Determine the maximum eigenvalue λ_{max}
- Identify the value RI
- Determine CI
- Identify CR
- Examine CR

Assessing the consistency of the paired comparisons was crucial for determining the AHP. Saaty (2008) claims that Eq. (2) has been used to compute the coherence of each matrix.

$$CR = \frac{CI}{RI} \quad (2)$$

Where CI stands for consistency index and RI for random index.

- Table 3.2 provides RI.
- Using Eq. (3), CI is determined as suggested by Saaty (2008):

$$CI = \frac{\lambda max - n}{n-1} \quad (3)$$

- λmax: the highest eigenvalue of the consistency vector,
- n: the quantity of each matrix's elements (criteria, sub criteria)

Tables 3.2 provide RI values for matrices with order (n) s ranging from 1 to 10.

Table 3-2 RI

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49
RI: Random consistency index										

Source: Saaty (2008)

7) **Step 7: Determine the total weights**

The AHP multiplies all the relative weights of each element in all levels after these steps are finished to provide a vector of overall weights for the last level.

8) Step 8: Making the ultimate choice

The final step starts by adding the relative values for each group of items across all levels of the hierarchy. The total score for the indications connected to the sub criteria layer is calculated by combining these values.

3.10. Ethical Consideration

The study's only goal of conducting educational research was guaranteed by the researchers. The names and addresses of survey respondents were not made public during the data collection and processing process. In the event that subsequent research is released, anonymity will always be maintained, and names won't be included without consent.

CHAPTER FOUR

4. RESULT AND DISCUSSION

This section presents data collected from the respondents. Based on the model, questionnaire was developed. Both AHP and Likert scale data are collected. AHP was used to prioritize technological capabilities. Likert scale data were used to assess technological capabilities.

4.1. Response Rate

The study distributed 50 questionnaires in total and 44 of the total number of questionnaires distributed were properly completed and returned. Therefore, 88% of respondents responded.

4.2. Data Collection and Analysis

The population considered under this study is researchers under Ethiopian manufacturing technology and engineering industries research and development center. The population size is 50 and all of which are located in manufacturing technology and engineering industries research and development center. Under the same categories, it is discovered that there is little variation in terms of nature, size, and business style. As a result, with this in mind, significant care and attention is paid to include an adequate number of researchers from each category.

4.3. Socio Demographic Characteristics of the Respondents

The socio demographic data of the survey's participating respondents businesses are shown in Table 4.1.

Table 4-1 Socio demographic characteristics

Socio demographic characteristics		Frequency	Percent
Age group	18-30	3	6.8
	31-40	35	79.5
	41-50	6	13.6
Sex	Male	38	86.4

Socio demographic characteristics		Frequency	Percent
	Female	6	13.6
Academic Qualification	Degree	39	88.6
	Masters	5	11.4
Year of service in MTREID	1 Year	4	9.1
	1 - 5 Year	14	31.8
	6-10 Year	22	50.0
	11 & above	4	9.1

Source: Author's

The majority of the respondent's (86.3%) were below 40 years. This shows that MTEIRDC researchers are young. The respondents mostly consisted of males (86.4%) and female (13.6%), this shows that there is much to do in female researchers in MTEIRDC context. Among academic qualification 88.6% of the respondents were first degree. This shows there is much to do with qualification of the workers. 90.9% of respondents had an experience of less than ten years in MTREIDC. This shows that there are less experienced researchers in MTEIRDC. To sum all up, the sample fits with the recent situation of MTREIDC and further analysis can be conducted by using this data.

4.4. Technological capability assessment using AHP Analysis

Questionnaire was developed following the methodology for the AHP, which was answered by 10 experts. Using a questionnaire, researchers were asked to evaluate each project in accordance with the major and supporting criteria. In order to facilitate the calculations, Spice Logic Analytical Hierarchy Process software was used. Priorities of criteria were prioritized according to the most strongly disagreed with or the most closely agreed with based on their individual and group judgments of the study group. To preserve the research's objectivity, the researchers were simply referred to as Researcher-1, Researcher-2, and Researcher-3 throughout the review procedure.

Priorities are calculated using the AHP methodology after matrices are formed based on ratings obtained from expert input.

For the case of prioritization of the criteria, after the aggregation process performed with the answers of the 10 experts, the comparison matrix of Table 4.2 to Table 4.7 was obtained. The AHP method was used to prioritize the indicators having a strong influence on the technological capability of MTEIRDC.

Table 4-2 Matrix of pairwise comparison with respect to technology

	Technology base	Innovation	Technical service	Technology Diffusion	Cooperation	Priorities
Technology base	1	5	5	8	4	0.5074
Innovation	0.2	1	5	5	3	0.2411
Technical service	0.2	0.2	1	0.5	0.333	0.0543
Technology Diffusion	0.125	0.2	2	1	0.333333333	0.0641
Cooperation	0.25	0.33333	3	3	1	0.1329

* Consistency Ratio calculated as 0.09

Source: Author's

Using Spice logic Analytical Hierarchy Software, priority for all levels of the hierarchy established with the AHP was obtained. From the analytical results shown in Table 4.2, "Technology base (0.5074)" was the most important dimension of critical factor to technological capability followed by "Innovation (0.2411)"; "Cooperation (0.1329)"; "Technology Diffusion (0.0641)" and "Technical service (0.1143)"

This result indicates that technology base capability and innovation capability are the most important issues for the company TCs, reflecting the fact that firms should place more emphasis on technologies base. Ultimately, technology diffusion and technical service are the lowest among the various aspects.

The numerous constructs in each dimension of the important technological competence factors have been ranked for each dimension at the third level of technological capability. Table 4.3 evaluates the constructs under dimension "technologies base" had been checked for hierarchy.

Table 4-3 Matrix of pairwise comparison with respect to technology base

Technology base 0.5074	Technology Strategy	Technical Infrastructure	Technical equipment and Software	Competences	Priorities
Technology Strategy	1	0.25	0.25	0.1666	0.0679
Technical Infrastructure	4	1	0.25	1	0.1979
Technical equipment and Software	4	4	1	2	0.4716
Competences	6	1	0.5	1	0.2625

* Consistency Ratio calculated as 0.09

Source: Author's

Table 4.3 shows that 'Technical equipment and Software (0.4716)' had been reported most important constructs in "Technology base", followed by 'Competences (0.2625)'; 'Technical Infrastructure (0.1979) and 'Technology Strategy (0.0679)'.

The third level of technological capability includes a variety of constructions that have been ranked for each dimension's important technological capability characteristics. Table 4.4 evaluates the constructs under dimension "innovation capability" had been checked for hierarchy.

Table 4-4 Matrix of pairwise comparison with respect to innovation capability

Innovation 0.2411	Innovative Technological Results	Design and pilot manufacturing	New Technological Solutions as Products Software	Priorities
Innovative Technological Results	1	2	5	0.5678

Innovation 0.2411	Innovative Technological Results	Design and pilot manufacturing	New Technological Solutions as Products Software	Priorities
Design and pilot manufacturing	0.5	1	4	0.3339
New Technological Solutions as Products	0.2	0.25	1	0.0981

* Consistency Ratio calculated as 0.021

Source: Author's

Table 4.4 reveals that "Innovative Technological Results" (0.5678), "Design and pilot manufacturing (0.3339)," and "New Technological Solutions as Products Software" (0.0981)" have been reported as the most important constructs in "innovation capabilities."

In the following table, the hierarchy of the constructs under the dimension "technical service" has been verified.

Table 4-5 Matrix of pairwise comparison with respect to technical service

Technical service 0.0543	Testing service	Quality of standards & certification service	Priorities
Testing service	1	0.2	0.1666
Quality of standards & certification service	5	1	0.8333

Source: Author's

According to Table 4.5, the most significant construct in the "technical service" dimension of a vital component to technological competency was "Quality of standards & certification service" (0.8333), which was followed by "Testing service" (0.1666).

In the following table, the hierarchy of the constructs under the dimension "technology diffusion" has been examined.

Table 4-6 Matrix of pairwise comparison with respect to technology diffussion

Technology Diffusion 0.0641	Consultancy	Training	Provide information services	Administer government programmes	Priorities
Consultancy	1	4	5	5	0.5459
Training	0.25	1	4	6	0.2903
Provide information services	0.2	0.25	1	1	0.0837
Administer government programmes	0.2	0.166667	1	1	0.0799

* Consistency Ratio calculated as 0.097

Source: Author's

According to the analytical findings in Table 4.6, the "Consultancy" construct (0.5459) was deemed to be the most significant in "technology diffusion," followed by "Training (0.2903)," "Provide information services" (0.0837)," and "Administer government programs" (0.0799)."

Hierarchy had been selected under the dimension "Cooperation" in the following table.

Table 4-7 Matrix of pairwise comparison with respect to cooperation

Cooperation **0.1329**	**Cooperation with external research organizations**	**Integration & usage of technologies from externals**	**Cooperation with Innovation Ecosystem**	**Priorities**
Cooperation with external research organizations	1	2	4	0.5793
Integration & usage of technologies from externals	0.5	1	1	0.2341
Cooperation with Innovation Ecosystem	0.25	1	1	0.1865

* Consistency Ratio calculated as 0.00036

Source: Author's

The most significant construct in the dimension "Cooperation" of technological capability has been determined to be "Cooperation with external research organizations" (0.5793), followed by "Integration & usage of technologies from externals" (0.2341) and "Cooperation with external research organizations" (0.1865).

It is important to infer here that values of consistency ratio are in acceptable range for various matrixes of pairwise comparisons shown in Table 4.2 to Table 4.7, ensuring reliability of researcher's judgment.

Table 4-8 Prioritization of criteria and subcriteria

Criteria and priority (%)	Sub-criteria	Priority (%)	Rank	Consistency test	Over all rank
Technology base 50.74%	Technology Strategy	0.0679 (6.79)	4	0.09< 0.1	1
	Technical Infrastructure	0.1979 (19.79)	3		
	Technical equipment and Software	0.4716 (47.16)	1		
	Competences	0.2625 (26.25)	2		
Innovation 24.11%	Innovative Technological Results	0.5678 (56.78)	1	CR 0.021 < 0.1	2
	Design and pilot manufacturing	0.3339 (33.39)	2		
	New Technological Solutions as Products/Software	0.0981 (9.81)	3		
Technical service 5.43%	Testing service	0.1666 (16.66)	2		5
	Quality of standards & certification service	0.8333 (83.33)	1		
Technology Diffusion 6.41%	Consultancy	0.5459 (54.59)	1	CR 0.097 <0.1	4
	Training	0.2903 (29.03)	2		
	Provide information services	0.0837(8.37)	3		

Criteria and priority (%)	Sub-criteria	Priority (%)	Rank	Consistency test	Over all rank
	Administer government programmes	0.0799 (7.99)	4		
Cooperation 13.29%	Cooperation with external research organizations	0.5793 (57.93)	3	CR 0.046< 0.1	3
	Integration & usage of technologies from externals	0.2341 (23.41)	2		
	Cooperation with Innovation Ecosystem	0.1865 (18.65)	1		

Source: Author's

The most significant criteria in the analysis are "technology base" (50.74%) and "Innovation" (24.11%). In the "technology base" sub-criteria, "technical equipment and software" (47.16%) comes out on top, followed by "competencies" (26.25%). This criteria analysis demonstrates that researchers are more focused on the Manufacturing Technology and Engineering Industries Research and Development Center's technology base technological capability. The analysis critically shows that research and development is much concerned about technical equipment and Software.

The criteria "innovation" is the second most priority among all with weight of 24.11%. Innovation is the results of research, development on the creation of innovative solutions. In the sub-criterion "innovative technological results" with 56.78 % weight is the first priority followed by "design and pilot manufacturing" with 33.39%. It shows that researchers also give due concern for innovation results. With 13.29% weight to the criteria "cooperation" is the third priority. Researchers first consider the technology base and then the result of innovation and then cooperation. With 6.41% weight, technology diffusion has the fourth position in the analysis. Technical service is the least important criteria among others with 5.43% weight.

The study calculated integrated priority (global priority) and integrated ranking by multiplying each sub-criteria weight with its main criteria weight, for example,.328*0.277= 0.090856 (integrated priority of sub-criteria (technology strategy) i.e. experiment likewise integrated priority (global priority) an integrated ranking. This allowed the study to better understand the priority of the criteria and sub-criteria.

Table 4-9 Overall ranking of all criteria

Criteria and priority	Sub-criteria	Priority	Rank	Integrated priority	Integrated ranking
Technology base 0.5074	Technology Strategy	0.0679	4	0.0344	9
	Technical infrastructure	0.1979	3	0.1004	4
	Technical equipment and software	0.4716	1	0.2392	1
	Competences	0.2625	2	0.1331	3
Innovation 0.2411	Innovative technological results	0.5678	2	0.1368	2
	Design and pilot manufacturing	0.3339	3	0.0805	5
	New technological solutions as products/software	0.0981	1	0.0236	12
Technical	Testing service	0.1666	2	0.0090	14

Criteria and priority	Sub-criteria	Priority	Rank	Integrated priority	Integrated ranking
service 0.0543	Quality of standards & certification service	0.8333	1	0.0452	7
Technology Diffusion 0.0641	Consultancy	0.5459	2	0.0349	8
	Training	0.2903	1	0.0186	13
	Provide information services	0.0837	4	0.0053	15
	Administer government programmes	0.0799	3	0.0051	16
Cooperation 0.1329	Cooperation with external research organizations	0.5793	1	0.0769	6
	Integration & usage of technologies from externals	0.2341	2	0.0311	10
	Cooperation with Innovation Ecosystem	0.1865	3	0.0247	11

Source: Author's

Table 4.9 displays the integrated priority (global priority) and integrated ranking (global ranking) terms for overall ranking. The outcome reveals that "Technical equipment and Software" is the sub-criteria with the greatest influence. One of the main criteria is innovative technology outcomes, expertise, technical infrastructure and design, and pilot manufacturing. Manage government programs, offer information services, and offer testing services are in the three last positions of priority. These findings showed how important technological capability was to researchers in the manufacturing technology and engineering industries research and development center.

4.5. Technological Capability assemement

Following completion of the questionnaire by the researchers, the results are added up, and the entire score is compared with the values listed in Table 2.8. The comparison produces a final result that shows the firm's technological capabilities. According to data collected by questionnaire, Table 4.10 shows the percentage of each of the 5 dimensions of the study. Table 4.10 shows the level of technological capability in each index.

Table 4-10 The level of technological capability dimension

Dimensions	**Indices**	**Net Score**	**Score of Indices (%)**	**Existing Gap (%)**
I. Technology Base				
Technology Strategy	Awareness of new usable technologies	1.26	25	75
	Effective and efficient resource planning	1.50	30	70
	Technology road mapping (external)	1.32	26	74
Average Result		**1.36**	**27**	**73**
Technical Infrastructure	Building(s)	1.74	35	65
	Maintenance of Infrastructure	2.62	52	48
Average Result		**2.18**	**43.5**	**56.5**
Technical equipment and Software	General and Specific Equipment/ Software	2.59	52	48
	Maintenance of Equipment / Software	3.12	62	38

Dimensions	Indices	Net Score	Score of Indices (%)	Existing Gap (%)
Average Result		**2.855**	**57**	**43**
Competences	Core Competences	3.15	63	37
	Formal Qualification of Staff	3.00	60	40
	Competence Development	3.29	66	34
Average Result		**3.15**	**63**	**37**
II. Innovation				
Innovative Technological Results	High-Quality Research Work (basic, applied and Experimental development)	1.24	25	75
	Technology Protection / IP	1.29	26	74
Average Result		**1.265**	**25.5**	**74.5**
Design and manufacturing	Design and applications engineering	4.09	82	18
	Prototyping or pilot batch	3.91	78	22
Average Result		**4**	**80**	**20**
New Technological Solutions as Products	Technology Road mapping (internal)	1.32	26	74
Average Result		**1.32**	**26**	**74**
III. Technical service				
Technical service	Testing	4.18	84	16
	Standards and certification	3.68	74	26
Average Result		**3.93**	**79**	**21**
IV. Technology diffusion				

Dimensions	Indices	Net Score	Score of Indices (%)	Existing Gap (%)
Technology diffusion	Consultancy	4.00	80	20
	Training	4.35	87	13
	Maintaining information services	4.59	92	8
	Administering government programmes	4.68	94	6
Average Result		**4.405**	**88.25**	**11.75**
V. Cooperation				
Cooperation with external research organizations	Universities	1.44	29	71
	Research and Development Centers	1.35	27	73
Average Result		**1.395**	**28**	**72**
Integration & usage of technologies from externals	Integration & Usage of Technologies from	1.41	28	72
	Service Providers	1.32	26	74
Average Result		**1.365**	**27**	**73**
Cooperation with Innovation Ecosystem	Start-Ups	2.76	55	45
	Incubators and Accelerators	2.15	43	57
Average Result		**2.455**	**49**	**51**
Total Average Result		**71.35**	**53**	**47**

Source: Author's

According to Table 4.10,the average answers to the questionnaire's add up to a total of 71.35. Hence, the survey company falls under the category of medium level technological capability based on table 2.8.

4.5.1. Technology Base

According to the respondents in table 4.10, the level of technology strategy was found to be 27% which is very low. The result may indicate that the management of the research and development center has low awareness for new usable technologies. Besides it shows that effective and efficient resource planning capability is low, which may limit the research and development center's performance and the ability to execute high-quality R&D work. Moreover, it shows the research and development center low capability to technology road mapping (external) that restricts the ability to plan strategically the integration of needed technologies into the own infrastructure in a long-term perspective. Although the center may lack technology strategy formulation capability, it is advisable to outsource for technology partners because technological strategy creation is a critical component of any successful firm's overall business plan. Technology strategy development at least supports the process by which appropriate visions, objectives, and priorities are formed and communicated throughout the organization.

A result from Table 4.10 to the technical infrastructure question was 43.5% which is low. All rooms, including offices and labs, as well as the technical networking of the rooms, are included in the building(s) in which the R&D center functions. But for more operation to be performed it need to be expanded. Maintenance of buildings and laboratories has to be done for facilities to be functional in the long term.

According to the respondents from Table 4.10, the level of technical equipment and software is 57% which is medium level. However, the results from Team - CSIR, (2018), shows that the existing machineries and equipment are old and non-functional, which contracts the result from the questionnaire. Hence, all equipment as well as technologies and software that are available and required should be fullilfilled in order to offer R & D services.

63% of respondents said their companies are technologically proficient, which is above average. However, the result from Team - CSIR, (2018), shows that there is non-availability of or limited availability of qualified manpower in different areas of specialization. A business with strong technological capabilities will understand how its distinct technology advantages set it apart from competitors and how to further improve its capabilities and knowledge to stay competitive (TADESSE, 2011).

4.5.2. Innovation capability

Table 4.10's responses from respondents on innovative results show that 25.67% of respondents agreed with their company's capabilities, while the remainder 74.33% took the opposing position, which is a very low percentage. Innovative technological outcomes can also be defined in terms of how well the R & D center is able to offer technical solutions customized to each customer. The intricacy and individuality of the needs are taken into account in this decision.

According to responses in Table 4.10, 80% of them agreed that their companies were capable of design and manufacture, whereas 20% disagreed. The business has spent a lot of time developing a variety of goods that serve as the foundation for its R&D efforts.

According to respondents in Table 4.10, 26% respondents agreed to their firm ability to road mapping internal technology developments. The R & D center can make long-term, strategic plans by assessing the predicted future developments of its own technological solutions as products (Hecklau et al., 2022).

4.5.3. Technical service capability

According to respondents in Table 4.10, 84% agreed for their firm testing service capability which is very high. The R&D center's ability to provide testing services will help it to create new goods. Besides, 74% of respondents in Table 4.10, agreed for their firm standards and certification capability which is above the average technological capability. Coordinating research and development (R&D) efforts to define future standards is one of the duties of standards organizations.

4.5.4. Technology diffusion capability

According to respondents in Table 4.10, 80% agreed for their firm ability to provide consultancy service which is very high. According to respondents in Table 4.10, 87% agreed for their firm ability to provide training service very high. According to respondents in Table 4.10, 92% agreed for their firm ability to provide information services. According to respondents in Table 4.10, 94% agreed for their firm ability to provide Administering government programmes. Hence, 88.25% agreed for their firm technology diffusion which is very high.

4.5.5.Cooperation capability

According to cooperation with external research organizations were the respondents result is 28% agreed for their firms are capable of cooperation with external research organizations and the remaining 74% claims not. Collaborating with universities and other educational institutions to jointly deliver research results and develop innovative solutions is critical to the successful delivery of R&D services.

According to the respondents' cooperation with innovation ecosystem found to be 49 % which is below average. The R & D centers may benefit from collaborating with smaller, newer businesses or start-ups for the purpose of enhancing their own service offerings (Hecklau et al., 2022). Start-ups that are creative and adaptable can fill up the knowledge gaps left by R&D centers.

4.6. Technological capability in different dimensions

Table 4.11 compares current technological capabilities for each dimension of technological capabilities with overall technological capabilities.

Table 4-11 Technological capability in different dimensions

Dimensions	Score	Average Score of Capability Percentage (%)	Desirable level (score 100 %)	Existing Gap (%)
Technology Base	23.59	43	100	57
Innovation	11.85	44	100	56
Technical service	7.86	79	100	21
Technology diffusion	17.62	88.25	100	11.75
Cooperation	10.43	35	100	65
Average	**71.35**	**57.85**	**100**	**42.15**

Source: Author's

Based on the above table technology diffusion is with 88.25% the highest average score of capability followed by technical service with 79% the average score of capability. The weakest technological capability is cooperation with 35% the average score of capability followed by technology base with 43% the average score of capability and innovation with 44% the average score of capability. Hence the company should work to increase the cooperation and technology base capability.

4.7. Overall score of technological capability

AHP and LS were used to gather the data, which was then combined to offer a practical tool that can aid in decision-making and subsequently improve technological skills.

Table 4.12 shows the overall score of technological capability assessment based on AHP analysis and technological capability assessment using Likert scale data.

Table 4-12 Overall score of technological capability assessment

Dimensions	Score Likert scale	Integrated Score AHP	Net Score
Technology Strategy	4.08	0.0344	0.140
Technical Infrastructure	4.36	0.1004	0.438
Technical equipment and Software	5.71	0.2392	1.366
Competences	9.44	0.1331	1.256
Innovative Technological Results	2.53	0.1368	0.346
Design and manufacturing	8	0.0805	0.644
New Technological Solutions	1.32	0.0236	0.031
Testing service	4.18	0.009	0.038
Quality of standards & certification service	3.68	0.0452	0.166
Consultancy	4	0.0349	0.140
Training	4.35	0.0186	0.081
Maintaining information services	4.59	0.0053	0.024
Administering government	4.68	0.0051	0.024

Dimensions	Score Likert scale	Integrated Score AHP	Net Score
programmes			
Cooperation with external research organizations	2.79	0.0769	0.215
Integration & usage of technologies from externals	2.73	0.0311	0.085
Cooperation with Innovation	4.91	0.0247	0.121

Table 4.12, which outlines technological competence, was created using an LS and the AHP. One of the main technological capabilities is the hardware and software, which is ranked top in the AHP ranking. The LS results show a low level of satisfaction with the technological competence for the same function. This demonstrates that, although being a very essential aspect, technical technical equipment and software only generates a very low degree of satisfaction; as a result, more focus should be placed on this in order to achieve a greater improvement in technological competence. Similar analysis and considerations can be applied to all the components, making it possible to determine the important technological capability using the AHP and the level of technological capability using the LS.

4.8. Discussion

Based on technological capability assessment result in Table 4.11, technological capabilities after "cooperation" with score of 35% percent, the most weakest dimension and "Technology diffusion" with score of 88.25 percent, is the most strongest. As can be seen the minimum gap is related to technology diffusion, and the largest gap is belonging to the dimensions of cooperation. The technological capability level of the company is located in the medium level.

However, using AHP "Technology base" has been found the most important dimension of critical factors to technological capability followed by "innovation (0.2411)";

“cooperation (0.1329)”; “technology diffusion (0.0641)”; and “technical service (0.0543)”.

The found differences across the different methods were logical and intuitive. Because Likert scale is different from AHP in their expected outcomes, also the scales used were different between the methods. The study provided information on the technological capabilities of MTEIRDC that were both strong and weak, despite the fact that the analysis methodologies did not have a strong capacity for explanatory power in forecasting technological competence. However, the research made it possible to draw data-driven conclusions about the potential root causes rather than just concluding that the technological capability that hinder MTEIRDC performance are susceptible to the hierarchical role. Based on the results of the discovered technological capabilities, a few potential research directions could aid in understanding the underlying processes by which the organization might anticipate improving its technological capability. In order to help decision-makers prioritize or choose one or more criteria from a large set of frequently conflicting criteria, multi-criteria analysis (AHP) was conducted.

The results suggest that employees seem to count more on technology base and innovation in aligning their organization with technological capability by expecting future improvement in these areas - whereas technical service seem to be limited by organizational constraints.

The result of this research has supported the result of research conducted by Wang et al., (2008), selecting a technological innovation criterion that achieves a compromising solution is critical to successful innovation activities.

4.9. Model Development

Based on the findings, the researcher identified criteria/sub-criteria hierarchy and constructed a Hierarchy Structural Model of technological capability of Manufacturing Technology Engineering Industries Research and Development Center as mentioned in figure 4.1.

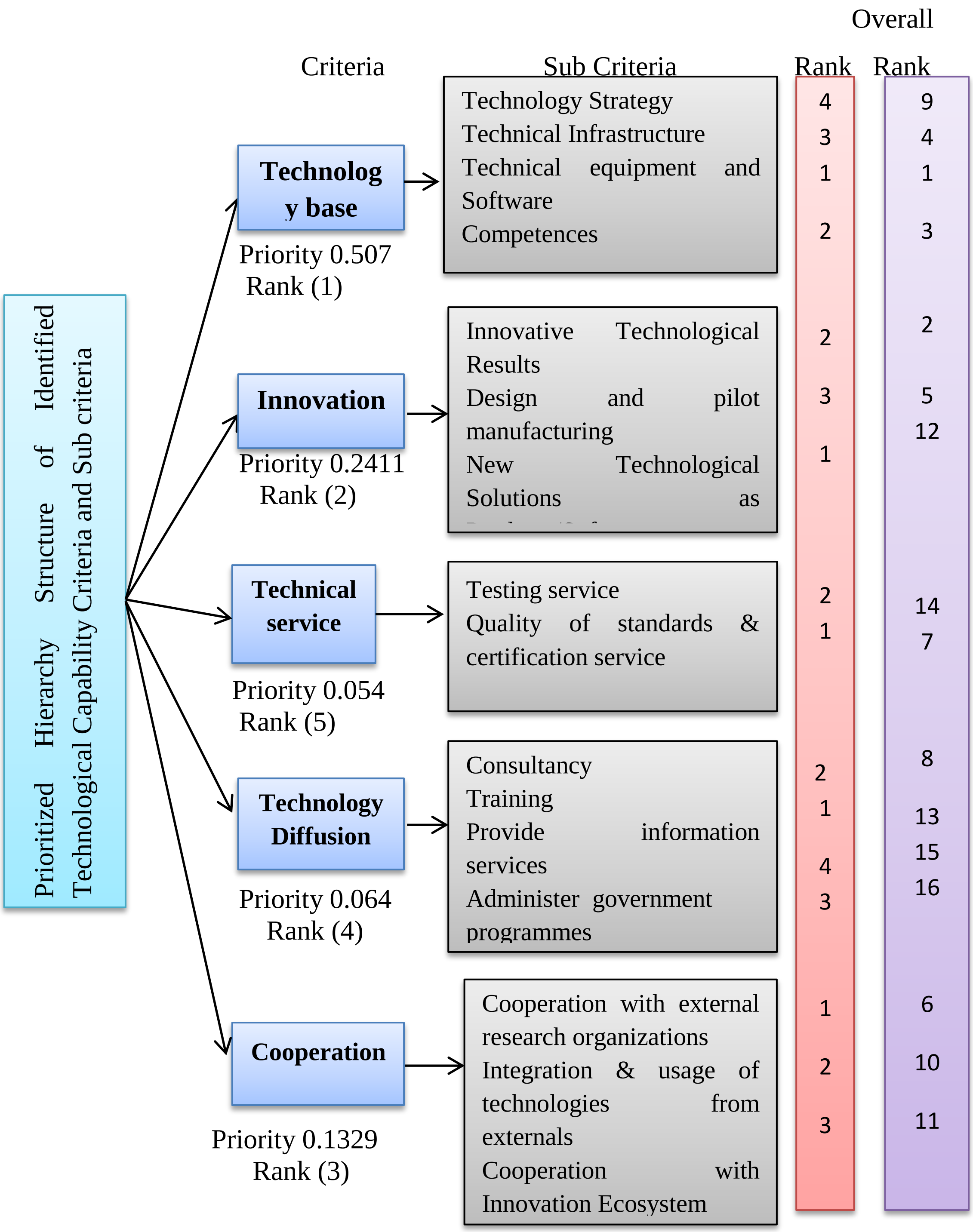

Figure 4-1 Hierarchy Structural Model

Source: Author's

In the figure 4.1, the researcher presented hierarchy structural model which identifies five criteria of technological capabilities and 16 sub criteria's for technological capabilities.

One of the most important results is that all criteria mentioned in the model above are important for research and development centers. However, from a practical perspective, research and development centers can identify the most influencing criteria and can enhance their technological capability. Hence, R & D centers should give more attention based on the order identified in figure 4.1: technology base, innovation, cooperation, technology diffusion, and technical service.

4.9.1. Technology base

Technology base include: technology strategy, technical infrastructure, technical equipment and software and competences. Technology base capabilities focuses on the tools and skills that R & D centers have at their disposal and utilize to carry out R&D initiatives. Technology base helps technologies to flow into the R&D centers. Hence, R & D centers must be proactive to upgrade its technologies base.

4.9.2. Innovation

Innovation include: innovative technological results, design and pilot manufacturing and new technological solutions as products/software. An organization's innovation capability reflects the ability of a company to consistently transform information and ideas into new products, processes, and systems. Results from R&D and the creation of original solutions are the main goals of innovation capabilities. As research and development centers master and develop new technologies, they move on to development. R & D centers support the innovation process by engaging in activities like: ideation, research (basic research, applied research, contract research), development, demonstration and production and business and market development.

4.9.3. Cooperation

Cooperation is integration of the R & D centers into local, regional, national, and even global innovation ecosystems in order to gain access to partners' complementary research competencies that is required for R & D project execution. Synergistic technical collaboration enables the R & D centers to access partners' technologies, equipment, and infrastructure that are required for the research effort, as well as their complementary research competencies.

4.9.4. Technology diffusion

Technologies are passed on to the R & D centers' customers via diffusion activities. Diffusion of technology entails much more than just adding new equipment to the company. It may be necessary to take additional steps, such as skill development, to realize the full potential of investments in new technology.

4.9.5. Technical service

Technical services are the most neglected technological capabilities in the research and development center technological capability assessment models. But they are important dimensions in which technologies affect, and are affected by, developments in technical services.

4.10. Key measures needed to improve the technological capability of the R & D center

The Technological capability of Manufacturing Technology and Engineering Industries Research and Development Center is classified at medium level based on the assessment done. Hence, the following key measures are needed to improve the technological capability of the research and development center.

a) Formulate technology policy

Technology policies are considered essential for the overall operation. A research and development center created expressly to establish technology-related policies and provide direction for initiatives involving the development of technological capabilities. As a result, the center needs to develop technological policies.

b) MTEIRDC must be proactive to upgrade its technology base

The center's ability to copy and innovate in terms of product and service is heavily reliant on the pressure to compete as well as the pressure to work together. Hence, a research and development center needs to upgrade its technology base to use state-of-the-art technologies in order to be able to provide high-quality products and services to its customers. New facilities hardware (buildings, machineries and equipment) and software have to be created to upgrade its technology base.

c) Promote cooperation

The primary way to address the improvement of technological capability within research and development center is by enhancing cooperation. The company must make an effort to improve its overall score and become a high level technological capability company, and in order to achieve this, it may choose to concentrate on reducing obstacles associated with the cooperation dimension. Research and development (R&D) centers must establish partnerships with universities and other R&D centers in order to maximize resources and create long-term impact. A viable option to developing skills internally is a strategy that facilitates access to capabilities through partnerships. The center must establish Cooperation Joint Conference system of the technological capability composed of relevant government leadership. Second, establish science and technological innovation Coordinating Committee composed of external research organizations to organize the implementation of technology planning and major projects.

d) Policy instruments to encourage technological capability building

Government should lay encouraging policies about investment in technology. These include the foreign exchange allocation system, preferential tax treatment, protection through tariff and/or quota measures, and tax exemption on imported capital goods and intermediate inputs.

Finally based on this study MTEIRDC is a medium-level technological capability company that has to advance gradually to a higher level. To do this, it is crucial to increase investments on cooperation and technology base.

4.11. Validation of the Model

The model shown in figure 4.1 is validated using face validity, which denotes that it has been reviewed by subject-matter experts with assistance from the author's. The interview question attached on appendix 3 were given to experts replied with the support of author. All experts are chosen from Manufacturing Technology and Engineering Industries Research and Development Center as well as from academician who is working in Addis Ababa University Institute of Technology. As per the discussion, the necessary dimensions are included in the existing models to assess technological capability of research and development centers. Hence, the proposed model is because it deals with real-world issues, it is pertinent and practicable.

CHAPTER FIVE

5. CONCLUSION AND RECCOMENDATIONS

5.1. Conclusion

To increase the technological capability and competitiveness of R & D centers, a technological capability assessment model must be developed. In this paper the author developed a model for technological capability assessment of research and development center. During the development of a model for technological capability assessment of research and development center, five technological capability dimensions were identified, which include a total of 16 sub criteria. To assess and rank the technological capabilities of R & D center, an integrated approach combining Likeret Scale approach and AHP is used. The use of both methodologies produced the data required to evaluate technological capabilities, enabling the decision-maker to determine which technological capability was the most useful and to advance MTEIRDC's technical capability. Technology base, innovation and cooperation received the highest priority. Whereas technological capability assessment showed the company is strong in technology diffusion and technical service and weak in cooperation and technology base. Technology capability level of the MTEIRDC is located in the medium level. Such type of company understands the need for better technological capabilities, but because they lack the internal resources, they are limited to responding to external demands rather than seizing opportunities. According to the case study, such an approach can offer a useful and efficient tool for evaluating the technological capabilities of R&D centers.

5.2. Recommendations

According to the findings, the following recommendations:

a. The creation of a technology strategy is essential for the development of successful technological capability and can enhance the technological capability that is directly tied to the ongoing expansion of organizations.

b. At the appropriate intervals, the research and development centers should assess technological capability using a technology capability assessment model created in this study. To ensure development and success, a regular examination and evaluation of the R & D center's technological capacity should be conducted.

c. In order to close the technology gap and achieve higher technological capacity, business executives must identify the right planning and improvement programs.

Finally, because technological capability assessment of research and development centers literature has been relatively scattered, the model developed in this study (Figure 4.1) may be a good starting point for new type of technology capability assessment in research and development center research.

On the basis of this work, the following research areas are suggested for future study:

a) AHP approaches are typically thought of as flexible and imprecise. Sensitivity analysis can be used to determine the impact of expert ratings and show how reliable the modified approach is.
b) For similar issues, various multi-criteria decision making procedures, such as Fuzzy AHP, ANP, etc., may be used, and the outcomes may then be further compared.

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Appendix-1 Questionnaire 1

Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Mechanical and Industrial Engineering (SMIE)

Industrial Engineering

Dear Sir/ Madam,

I am a student in Addis Ababa University and currently conducting a research entitled, "TECHNOLOGICAL CAPABILITY ASSESSMENT AND MODEL DEVELOPMENT IN RESEARCH AND DEVELOPMENT CENTER: The Case of Manufacturing Technology and Engineering Industries Research and Development Center in Ethiopia)" for Partial Fulfillment of the Award of Master's degree in Industrial Engineering Stream.

This questionnaire is prepared to assess technological capability of Manufacturing Technology and Engineering Industries Research and Development Center. Your input is very important to the research hence you are kindly requested to fill this questionnaires to achieve the grand objective of the study. This study is anonyms and your response will be kept highly confidential and used only for this research.

I thank you very much in advance for participating in this survey and providing your thought full feedback.

Tereda Tafesse ________________

Mob: 0913910828

Email: teretafe123@gmail.com

Technological capability: refers to our capability (capacity) to use technologies in a way that contributes to effective and successful achievement of our purposes

(Štrukelj & Dolinšek, 2011).

I. Personal information

1. Age group A, 18-30 ☐ B, 31-40 ☐ C, 41-50 ☐ D, Above 50 ☐

2. Sex: Male ☐ Female ☐

3. Academic qualification: 1-12 Grade ☐ Diploma Degree ☐

Master's degree ☐ PHD & above ☐

4. Year of service at MTEIRDC 1 Year ☐ 1-5 Year ☐ 6-10Year ☐

11 & above ☐

II. Please insert a tick mark (√) where you think is appropriate in the space

Key Questions	**Strongly Disagree**	**Disagree**	**Not sure**	**Agree**	**Strongly Agree**
Assessment Score	1	2	3	4	5
1) Technology Base					
1.1. Technology Strategy					
1. Our organization is well aware of new usable technologies besides the very structure approaches of technology foresight and technology road mapping					
2. Our organization effectively and efficiently plan technology resources					
3. Our organization externally roadmap technology to					

Key Questions	Strongly Disagree	Disagree	Not sure	Agree	Strongly Agree
Assessment Score	1	2	3	4	5
integrate needed technologies into the own infrastructure in a long-term perspective					
1.2. Technical Infrastructure					
4. Our organization has buildings which contains all rooms, such as laboratories and offices and the technical networking of the rooms					
5. The technical infrastructure, such as buildings and laboratories are maintained and serviced in order to be functional in the long term.					
1.3. Technical equipment and Software					
6. Our organization has all basic equipment as well as technologies and software that are available and required to fulfill the services.					
7. The existing general and specific main equipment are maintained and serviced in order to be available in the					

Key Questions	Strongly Disagree	Disagree	Not sure	Agree	Strongly Agree
Assessment Score	1	2	3	4	5
long term as a resource for performing research services and developing products.					
1.4. Competences					
8. Our organization has technological core competences represent bundles of technologies and capabilities with a concrete application reference					
9. Our organization has various competence areas of employees such as professional degrees, certifications etc.					
10. The R & D center proactively contribute to the employee competence development by providing internal or external trainings and education.					
2) Innovation capability					
2.1 Innovative Technological Results					
11. Our organization perform high-quality research work for successful creation of					

Key Questions	Strongly Disagree	Disagree	Not sure	Agree	Strongly Agree
Assessment Score	1	2	3	4	5
innovative technological solutions					
12. Our organization protects its own technologies through effective intellectual property management (patents and licenses)					
2.2 Design and pilot manufacturing					
13. Our organization's high technological capability lead to high quality design and applications engineering					
14. Our organization's high technological capability lead to a high quality of prototyping or pilot batch manufacturing of new products offered by the R & D center					
2.3 New Technological Solutions as Products					
15. Our organization road map internal technology developments					
3) Technical service capability					

Key Questions	Strongly Disagree	Disagree	Not sure	Agree	Strongly Agree
Assessment Score	1	2	3	4	5
3.1 Testing service					
16. Our organization high technological capability lead to a high quality of testing service					
3.2 Quality of standards and certification service					
17. Our organization high technological capability lead to a high quality of standards and certification service					
4) Technology diffusion capability					
4.1 Consultancy					
18. Our organization provide consultancy with the aim of developing innovative solutions					
4.2 Training					
19. Our organization provide training					
4.3 Provide information services					
20. Our organization provide information services					

Key Questions	Strongly Disagree	Disagree	Not sure	Agree	Strongly Agree
Assessment Score	1	2	3	4	5
4.4 **Administer government programmes**					
21. Our organization administer government programmes					
5) Cooperation capability					
5.1 Cooperation with external research organizations					
22. Our organization collaborate with universities and other educational institutions with the aim of jointly providing research results and developing innovative solutions					
23. Our organization provides joint research performances and develops innovative solutions, synergistic collaboration with other Research and Development Center.					
5.2 Integration & usage of technologies from externals					
6 Our organization collaborate for the use and integration of third-party technologies and services					

Key Questions		Strongly Disagree	Disagree	Not sure	Agree	Strongly Agree
Assessment Score		1	2	3	4	5
7	Our organization collaborate to leverage end-user technologies and technology services that are needed to deliver or accelerate the targeted research performance.					
5.3	**Cooperation with Innovation Ecosystem**					
6	Our organization cooperates with smaller and young companies / start-ups for its own service provision.					
7	Our organization cooperates with incubators and accelerators for further networking with start-ups and young companies.					

Appendix-2 Questionnaire 2

Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Mechanical and Industrial Engineering (SMIE)

Industrial Engineering

Dear Sir/ Madam,

I am a student in Addis Ababa University and currently conducting a research entitled, "TECHNOLOGICAL CAPABILITY ASSESSMENT AND MODEL DEVELOPMENT IN RESEARCH AND DEVELOPMENT CENTER: The Case of Manufacturing Technology and Engineering Industries Research and Development Center in Ethiopia)" for Partial Fulfillment of the Award of Master's degree in Industrial Engineering Stream.

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I thank you very much in advance for participating in this survey and providing your thought full feedback.

Tereda Tafesse

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Mob: 0913910828

I. Personal information

1. Age group A, 18-30 ☐ B, 31-40 ☐ C, 41-50 ☐ D, Above 50 ☐

2. Sex: Male ☐ Female ☐

3. Academic qualification: 1-12 Grade ☐ Diploma ☐ Degree ☐ Master's degree ☐ PHD & above ☐

4. Year of service at MTEIRDC 1 Year ☐ 1-5 Year ☐ 6-10Year ☐ 11 & above ☐

II. Please read the following questions carefully and mark (√) the appropriate check box in the pair wise comparisons' table.

Instruction:

Please trace the table row by row.

If you believe that the factor located in the right column of the table is more important than the factor in the left column (located in the same row) then mark one of the checkboxes located in the right side of equal. You can choose one of the check boxes based on the level of importance in comparison of the two factors. If you believe that the factor located in the left column of the table is more important than the factor in right column (located in the same row) then mark one of the check boxes located in the left side of equal. You can choose one of the check boxes based on the level of importance in comparison of the two factors.

Note 1: From right to left, importance of right factor in comparison to the left decreases.

Note 2: Please consider the logical consistency of your answer. For instance consider table below: If you marked "Technologies base" extremely important in comparison to "Innovation" and marked "Innovation" extremely important in comparison to "Technical service" then your judgment would be "Technologies base" extremely important than "Technical service".

1.Please determine the importance and priority of factors in the right side of this table compared to the factors in the left side regarding "MTEIRDC Technological capability". (For instance in the first row of the table please determine how important are "Technologies base" and "Innovation" compared to each other regarding "MTEIRDC Technological capability". For more information about the factors, see the questionnaire below. The white column shows important level between two levels.

	Extremely Important **(9)**	8	Vvery strongly Important**(7)**	6	Strongly Important**(5)**	4	Slightly Important**(3)**	2	Equal**(1)**	2	Slightly Important**(3)**	4	Strongly Important**(5)**	6	Vvery strongly Important**(7)**	8	Extremely Important**(9)**	
Innovation																		Technologies base
Technical service																		Technologies base
Technolog y Diffusion																		Technologies base
Cooperati on																		Technologies base
Technical service																		Innovation
Technolog y Diffusion																		Innovation
Cooperati on																		Innovation
Technolog y Diffusion																		Technical service
Cooperati on																		Technical service
Cooperati on																		Technology Diffusion

2. Please determine the importance and priority of factors in the right side of this table compared to the factors in the left side regarding “Technology Base”. (For instance in the first row of the table please determine how important are “Technology Strategy” and “Technical Infrastructure” compared to each other regarding “Technology Base”. For more information about the factors, see the questionnaire below. The white column shows important level between two levels.

	Extremely Important (9)	8	Vvery strongly Important(7)	6	Strongly Important(5)	4	Slightly Important(3)	2	Equal(1)	2	Slightly Important(3)	4	Strongly Important(5)	6	Vvery strongly Important(7)	8	Extremely Important(9)	
Technical Infrastructure																		Technology Strategy
Technical equipment and Software																		Technology Strategy
Competences																		Technology Strategy
Technical equipment and Software																		Technical Infrastructure
Competences																		Technical Infrastructure
Competences																		Technical equipment and Software

3. Please determine the importance and priority of factors in the right side of this table compared to the factors in the left side regarding "Innovation capability". (For instance in the first row of the table please determine how important are "Innovative Technological Results" and "Design and pilot" compared to each other regarding "Innovation capability". For more information about the factors, see the questionnaire below. The white column shows important level between two levels.

	Extremely Important (9)	8	Vvery strongly Important(7)	6	Strongly Important(5)	4	Slightly Important(3)	2	Equal(1)	2	Slightly Important(3)	4	Strongly Important(5)	6	Very strongly Important(7)	8	Extremely Important(9)	
Design and pilot manufacturing																		Innovative Technological Results
New Technological Solutions as Products Software																		Innovative Technological Results
New																		Design and

	Extremely Important **(9)**	8	Vvery strongly Important**(7)**	6	Strongly Important**(5)**	4	Slightly Important**(3)**	2	Equal**(1)**	2	Slightly Important**(3)**	4	Strongly Important**(5)**	6	Very strongly Important**(7)**	8	Extremely Important**(9)**	
Technological Solutions as Products Software																		pilot manufacturing

4. Please determine the importance and priority of factors in the right side of this table compared to the factors in the left side regarding “Technical service capability”. (For instance in the first row of the table please determine how important are “Testing service” and “Quality of standards and certification service” compared to each other regarding “Technical service capability”. For more information about the factors, see the questionnaire below. The white column shows important level between two levels.

	Extremely Important **(9)**	8	Vvery strongly Important**(7)**	6	Strongly Important**(5)**	4	Slightly Important**(3)**	2	Equal**(1)**	2	Slightly Important**(3)**	4	Strongly Important**(5)**	6	Vvery strongly Important**(7)**	8	Extremely Important**(9)**	
Quality of standards and certification service																		Testing service

5. Please determine the importance and priority of factors in the right side of this table compared to the factors in the left side regarding “Technology diffusion capability”. (For instance in the first row of the table please determine how important are “Consultancy” and “Training” compared to each other regarding “Technology diffusion capability”. For more information about the factors, see the questionnaire below. The white column shows important level between two levels.

	Extremely Important (9)	8	Vvery strongly Important(7)	6	Strongly Important(5)	4	Slightly Important(3)	2	Equal(1)	2	Slightly Important(3)	4	Strongly Important(5)	6	Vvery strongly Important(7)	8	Extremely Important(9)	
Training																		Consultancy
Provide information services																		Consultancy
Administer government programmes																		Consultancy
Provide information services																		Training
Administer government programmes																		Training
Administer government programmes																		Provide information services

6. Please determine the importance and priority of factors in the right side of this table compared to the factors in the left side regarding "Cooperation capability". (For instance in the first row of the table please determine how important are "Cooperation with external research organizations" and "Integration & usage of technologies from externals" compared to each other regarding "Cooperation capability". For more information about the factors, see the questionnaire below. The white column shows important level between two levels.

	Extremely Important (9)	8	Vvery strongly Important(7)	6	Strongly Important(5)	4	Slightly Important(3)	2	Equal(1)	2	Slightly Important(3)	4	Strongly Important(5)	6	Vvery strongly Important(7)	8	Extremely Important(9)	
Integration & usage of technologies from externals																		Cooperation with external research organizati

	Extremely Important **(9)**	8	Vvery strongly Important**(7)**	6	Strongly Important**(5)**	4	Slightly Important**(3)**	2	Equal**(1)**	2	Slightly Important**(3)**	4	Strongly Important**(5)**	6	Vvery strongly Important**(7)**	8	Extremely Important**(9)**	
																		ons
Cooperation with Innovation Ecosystem																		Cooperation with external research
Cooperation with Innovation Ecosystem																		Integration & usage of technologies from externals

Appendix III: Interview Guide for Model Validation

1. Do you find the suggested approach useful for assessing a research and development center's technological capabilities?

2. How is relevant the proposed technology capability assessment model to increase the performance of the center

3. Are you satisfied with the criteria's considered in the model to increase the performance of the center?

5. Pros and cons of implementing the proposed models in your company?