An investigation into the technology transfer barriers of the electronic train control systems installed on the South African railway network – A study into SA's freight rail operator

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Technology transfer is the process of moving technology for use and understanding from one organisation to another for the technology recipient to achieve and implement technology developments and innovations. The technology transfer process is a complex, volatile and iterative one, which requires the flow of information and knowledge between the transferor and the transferee. This qualitative research aims to identify and investigate barriers to the technology transfer of the electronic train control projects undertaken by a South African freight rail operator (FRO) to upgrade its train control systems on several pilot sites. Ten staff members involved in the FRO's project management, maintenance, operations and training functions were interviewed. They have worked or are working on the various installed electronic train control systems. The thematic analysis findings revealed that the FRO is not equipped to exploit and further develop the technology. The barriers that contribute to this include the loss of vital skills internally, the project management of these technology transfer projects and the lack of flexibility of the technology regarding the local conditions and requirements of the FRO. The broadly analysed impact of the loss of skills in freight rail operations resulted in skills retention, adding to the initially proposed research model as a factor that contributes to the technology transfer process alongside learning, the transferor and transferee environment, language and procurement. Including a technology transfer office (internally or externally) could mitigate most of the identified barriers.

Index terms **— Electronic train control, railway innovation, technology transfer, transferee, transferor.**

I. Introduction

Over the past few years, South Africa's freight rail operator (FRO) has embarked on various projects to upgrade its train control systems to electronic systems due to the failure of the analogue train control systems installed over 30 years ago that will soon be obsolete. A train control system ensures the safe movement and control of trains and ensures that there are no conflicting movements [1].

The FRO has completed several pilot projects of various original equipment manufacturers (OEMs)' electronic train control systems, which were developed from international rail systems. However, these new technologies have not been rolled out to the FRO's entire network. Using advanced foreign technology requires the implementation of the technology transfer process to exploit the technology. Technology transfer entails the technology recipient moving technology for use and understanding from one organisation to another to achieve and implement technology developments and innovations [2].

The previous analogue system was developed and designed internally in the FRO. However, these new electronic systems have been developed and designed by their respective OEMs, leaving the railway operators with little knowledge to further develop, maintain and operate them efficiently. Previous research has indicated several contributors to the successful technology transfer of any technology product. If the technology owner and recipient do not handle it with integrated efforts, the technology and its operations can fail. This research explores the barriers that the FRO, as a recipient of electronic train control technology, and various electronic train control OEMs, as technology owners, face in fully transferring these technologies. The technology transfer is identified as not being fully successful due to the observation of a lack of optimal operations and maintenance of the technology by the FRO.

To address the problem, this research project aimed to identify and investigate the barriers to technology transfer that contribute to the less-than-optimal operation and maintenance of the electronic train control systems installed on South African railway lines.

The research answers the following questions:

- What are the technology transfer barriers between the OEMs and the FRO?
- How do the identified technology transfer barriers affect the operation and maintainability of the electronic train control systems installed on the FRO's rail networks?
- What measures can be implemented to overcome the identified barriers to technology transfer?

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- What are the roles of the transferor (the OEM) and the transferee (the FRO) in mitigating the technology transfer barriers?

The subsequent sections of this article detail the literature review conducted to develop the conceptualised research model. The research model is then used to develop a questionnaire and analyse the data collected qualitatively. The results are then presented, and the conclusions and recommendations are detailed.

II. Theoretical background

A. Train control system

The train control system is essential to ensure the safe movement and control of rail traffic [1]. The train control system has the simple task of fail-to-safety, which ensures that, in the event of a failure, the system fails to reach a safe state to stop or prevent the further movement of the train [1]. Another important factor in train control is protection against the conflicting movement of trains, which is affected by the interlocking of railway trackside equipment [1]. In computer-based or electronic train control systems, the control logic is encoded in software, directing the operation of the trackside equipment hardware [1]. With significant technological advancements, the train control system has evolved into a complex system, combining software and hardware, which requires individuals working with the system to understand its construction, the functionality of each subsystem and the integration of all system components.

B. Technology transfer

Technology transfer is a process that involves understanding, using and reproducing technology, including adaptation to local conditions and integration with existing technologies to achieve and implement technology developments and innovations [2]. Omar et al. [3] describe technology transfer as the process of transferring knowledge and skills from one person or organisation to another. This definition is confirmed by Mokmin et al. [4] to be an integrated process that involves the technology provider (transferor), recipient (transferee), product of transfer (technology) and transfer mechanisms. Technology transfer can potentially improve an organisation's competitiveness and performance by enhancing and transforming technology into value-adding activities [3]. Chege et al. [5] agree with the contributions that technology transfer can make to a country's economic development.

Successful global technology transfer plays a vital role in enabling access to international knowledge and technology, with the potential of growing local capabilities [2]. However, the technology transfer process in the automotive industry showed a low success rate of technology transfer in various projects worldwide [4]. Mokmin et al. [4] describe technology transfer success in terms of cost, budget and time, the usefulness of the technology to the transferee, the amount of knowledge of the technology transferred and the value created by the technology to the transferee organisation. Technology transfer is a back-and-forth process, and entails the flow of information and knowledge between the transferor and the transferee. This very characteristic of technology transfer makes it a complex and volatile process [4].

C. Role players in technology transfer

The most essential elements in technology transfer are the transferor, the transferee and the technology [6]. The transferor is the owner of the technology and knowledge, and the transferee is the receiver of the technology and knowledge [6]. Technology transfer cannot be left to unfold between the transferor and the transferee, as several elements need to be considered. Otherwise, the transferee is left with user manuals and layouts of the technology they know very little of [6]. In the case of this research, the transferors are the electronic train control system OEMs. The FRO is the transferee and the electronic train control is the technology. The transferee or receiver of the technology is responsible for taking advantage of it to create more innovation opportunities for itself [7].

The historic relocation of the transfer agents (transferors) from Britain to the colonies, such as India and South Africa, led to the transfer agents having a significant supervisory role, not only in the construction, but also in the railway operations [8]. This led to an ongoing technology transfer process, creating dependency on the transferor as complex rail operations evolved [8]. Kerr [8] highlights the crucial requirement of socio-technical training and a change of mindset among local labour before the construction and operations could commence. The construction phase allowed for local labour processes' adaptability versus the operations, which forced conformity to the British labour processes [8].

D. Technology transfer models

Khabiri et al. [6] conceptualised a technology transfer model based on the broadcasting transfer model, emphasising the involvement of the transferee in all the stages in the technology transfer process. The bidirectional relationship between the transferor and the transferee allocates greater significance to the transferee's role than in earlier models [6]. Another model by Arenas and González [7] simplifies technology transfer as a communication process between a sender (transferor) and a receiver (transferee), where the message is the transferred technology. The commonality between the different presented models analysed by Arenas and González [7] is the presence of the transferor and the transferee. The most significant difference is the communication or mechanism of the transfer process.

Jibat [2] used the technology transfer life cycle model to assess the contribution of the Addis Ababa Light Rail Transit (AA LRT) project in introducing new city transportation technology, including a train control system that measures up to international standards. The AA LRT was a new technology project for city passenger transportation in Ethiopia. Chinese Railway Engineering and Construction (CREC) used various OEMs to construct the rail systems in the AA LRT. This project introduced new technology to the country, and the Ethiopian government implemented a systematic technology transfer plan to allow the participation of local technology recipients. Therefore, Jibat [2] focused on reviewing the effectiveness of Ethiopia's technology transfer strategy, policies and processes during the AA LRT project's execution, noting the associated barriers to implementing the technology transfer.

E. Technology transfer barriers

From the study conducted by Omar et al. [3], the barriers to technology transfer can be categorised as follows:

- Learning environment
- Transferor and transferee environment
- Language barrier
- Barrier in procurement options

Several mechanisms can be used to mitigate these potential barriers, including measuring the effectiveness of the technology transfer, effective communication and the documentation of processes and methodologies [5]. Beukman and Steyn [9] looked at the required project phasing for technology transfer projects in South Africa. Their findings identified the causes of the failure of technology transfer projects for socio-economic development under the following categories: technical and external factors, project management, stakeholders and beneficiaries, and the suggested solutions under the different project stages or phases [9]. Some identified causes of failure relate directly to the project phasing, including insufficient planning before project execution, failure of due diligence during the feasibility studies and project piloting [9].

In summary, the literature review covers the developments made on the South African railways, focusing on train control systems. Further, the review of train control systems identified their crucial role in the safe operation of the rail network and the movement of trains. The need to keep up with technological advances in train control systems is essential in ensuring a decrease in network unreliability and breakdowns. Therefore, internationally rated train control systems are required to achieve efficiency in South Africa's rail operations, providing a global competitive advantage to the rail operator and the country. The subsequent section elaborates on the proposed conceptual framework derived from evidence gathered in the literature.

III. Proposed Conceptual Framework for Technology Transfer

Many technology transfer models have been developed over the past few years because of the challenges faced in technology transfer projects [2]. These models have been proposed and developed as tools to facilitate the effective planning and implementation of technology transfer in projects [2].

Key elements within the technology transfer process are identified as follows [2]:

- The transferor
- The transferee
- The transfer object (the technology and associated information and knowledge being transferred)
- The transfer mechanism
- The transfer factors contributing to the success of the transfer

According to the proposed model by Jibat [2] and Mokmin et al. [4], it is confirmed that the technology transfer process model requires the transfer of a product (technology) between the transferor and the transferee through a transfer mechanism. The transfer mechanism can be viewed as the structured execution of a technology transfer project [9].

This is reinforced by Arenas and González [7], who describe the transfer mechanism as the tool that enables technology transfer.

Khabiri et al. [6] also showed the bidirectional relationship between the transferor and the transferee in the proposed model. This is particularly relevant as the FRO needs to give input to the OEMs on how the technology should adapt to local conditions and existing systems within the FRO. Arenas and González [7] define the comments by the transferee to the transferor as feedback. Therefore, the concept framework introduced in this research (Fig. 1) is derived from the models presented by Jibat [2], Omar et al. [3], Arenas and González [7] and Khabiri et al. [6].

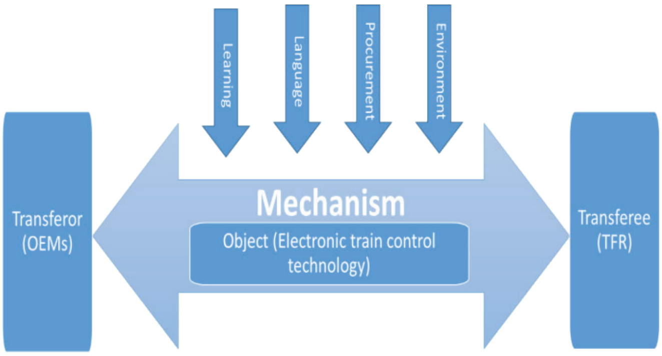

Fig. 1. Conceptual technology transfer framework (Source: Own research)

The research focuses on determining the barriers to the successful technology transfer of electronic train control systems to the FRO from the OEMs. From the literature, these barriers arise under four categories [3]. These are a learning environment, the transferor and transferee environment, language and procurement options.

A. Learning environment

A learning environment refers to the ability of the transferor and the transferee to learn from each other and teach each other. Effective technology transfer must be facilitated in a proactive learning environment. A relationship of mutual trust must exist between the transfer agents. This will bridge the gap between learning and teaching; hence a learning culture and environment must be built [3]. This learning culture should align with the organisation's existing culture to create a platform for better understanding between the transfer agents [3]. The relationship or interaction between the role players in the technology transfer is bidirectional, as presented in the research and other literature-based frameworks. The technology transfer process is characterised by colonial power from the transferor, which may imply a unidirectional interaction between the transfer agents; however, the need for adaptation to local conditions is emphasised [8].

Capacity building with the transferee is essential in the technology transfer process, as the goal of the technology transfer is for the transferee to develop further and exploit innovation opportunities arising from the transferred technology. The transferee beneficiaries should then be upskilled to use and manage the transferred technology [9].

B. Transferor and transferee environment

The transferor and transferee environment refers to creating an environment where both parties understand their role in the transfer process. The transferor is willing to transfer the appropriate technology, and the transferee intends to adopt the technology know-how. A gap or misalignment in this understanding has the potential to lead to unsuccessful technology transfer during project execution [3]. This can be viewed as representing the mindset and attitudes of both the transferor and the transferee. The model presented by Arenas and González [7] notes the greater environmental factors that affect the technology transfer process. Khabiri et al. [6] acknowledge the existence of factors in the greater environment that influence the success of technology transfer.

C. Language

Language refers to the language and communication understanding between the parties involved in the technology transfer. This can be broadly viewed as the communication language, technical language and business language used in the process. People involved in the technology transfer process come from different cultural, working and educational backgrounds. This contributes to the challenges faced in communication. Successful technology transfer relies on effective communication, and its absence can foster mistrust between the parties involved [3]. Communication within the transfer process is explained as the communication of the technology between the transferor and the transferee [3]. The result of the technology transfer is a technology that is successfully communicated to the transferee, ensuring that the transferor has considered all the communicated requirements.

D. Procurement options

Procurement options refer to the project management inputs required for the successful execution of technology transfer projects. Beukman and Steyn [9] identified the cause of technology transfer failure to be being directly linked to the management and phasing of the projects. The technology transfer process occurs within the boundaries of implementing a project; therefore, the successful management of the project leads to a better chance of successful technology transfer. The design-bid-build (tender) principal method has been extensively used over the past years for projects and has posed a challenge for technology transfer. Under this method, the tenderer (transferor) is required to complete the design process before the tender stage, making it difficult for the transferee to be involved in that stage of the design to obtain programmatic and technological design knowledge [3]. All stakeholders need to be identified and involved at the beginning of the transfer model to be aligned with the project objectives and plan and obtain buy-in [9].

In summary, the proposed conceptual framework captures four critical factors that are essential for technology transfer: learning, the transferor and transferee environment, language and procurement. A detailed explanation of the research methodology employed in this research is discussed in the following section.

IV. Research Method

The research took a qualitative approach with a descriptive research design as the study aimed to determine the instances on a case or project basis. Qualitative research is an “emergent, inductive, interpretive and naturalistic approach to the study of people, cases, phenomena, social situations and processes in their natural settings to reveal in descriptive terms the meanings that people attach to their experiences in the world” [10]. The qualitative approach worked best for this research, as it aimed to identify the barriers experienced in technology transfer, assess their impact, and explore solutions, focusing on various electronic train control projects implemented by the FRO with different OEMs.

A. Informants

Data was collected from the FRO project management, operations, maintenance and training personnel who have worked with the various installed electronic train control systems. These informants provided insights related to the factors stipulated in the concept framework depicted in Fig. 1. The aim is to obtain the transferee's perspective in the technology transfer process.

1) Project team

The project team resources involved in designing, constructing and testing the electronic train control systems, working with the various contracted OEMs, include the project managers and engineers involved in the project's execution. These resources are essential in the procurement factor identified in the conceptual technology transfer framework (Fig. 1). Project management inputs contribute to executing the technology transfer process and indicate how far the FRO, as the transferee, is involved in the design process. By interviewing these resources, the study aimed to determine the technology transfer barriers at the project design and execution stages and how these affected the project handover to both the FRO's operations and maintenance teams.

2) Maintenance team

The maintenance personnel is responsible for maintaining the installed electronic train control systems in their sections along the FRO's rail network. Their involvement in the project execution stages is limited, and they focus on familiarising themselves with the electronic control system, debugging and fault-finding. There is limited exposure during the project execution due to the project's time and budget constraints. These resources are then handed over entirely to the system at project close-out. The OEM is still bound to provide maintenance support to the FRO over a stipulated period, extending the technology transfer process beyond the project close-out. The maintenance team resources include the maintenance managers and technicians responsible for the sections where the various electronic train control systems are installed. They mainly speak to the transferor and transferee environment factor, as depicted in the conceptual framework (Fig. 1).

3) Operations team

These individuals operate the installed electronic train control systems within their sections. They encounter the technology once the project team has installed it and handed it over to them.

They are then expected to understand the operating philosophy developed in the engineering design. These informants mainly speak to the language factor in the technology transfer conceptual framework in Fig. 1, as it becomes vital that the engineering design and philosophy of the technology are translated into a language that operations can understand and adapt to. This group includes the train control officers and operations section managers responsible for the efficient operations of the trains by utilising the visual control unit (end-user interface) of the electronic train control systems [1].

4) Training facilitators

These individuals are involved in developing and facilitating training programmes for the FRO. In technology transfer projects, the FRO stipulates training requirements from the contracted OEM, such as training the trainer. These resources inform how these processes are undertaken to ensure that the relevant FRO resources are trained on the electronic train control systems. Referring to the conceptual framework in Fig. 1, these training facilitators can talk about the learning environment factors that influence the transfer of the technology.

Further on, efforts were made to collect data from a selected number of OEM contractors, who are anticipated to serve as the transferors of the technology; however, no response was received from the requested participants. These participants would have contributed to the factors stipulated in the conceptual framework in Fig. 1 to obtain the transferor's perspective in the technology transfer process. The secondary data was also analysed to identify and investigate the technology transfer barriers. This includes project documentation, maintenance manuals and records, operations philosophy and operations records of faults, challenges and issues logs to complement the interview responses received from the above-detailed informants.

B. *Research instrument*

The research instrument selected for this research was semi-structured interviews. The research participants were interviewed online to determine their experience in the technology transfer projects of the various electronic train control systems installed on the FRO's rail network. Interview questions were developed to align with the factors in the conceptual framework and tailored for the research participants.

C. *Data collection and analysis*

The data was collected from individuals who were or are involved in the electronic train control projects: the maintenance and operations personnel who work with the various OEM technologies, and the training personnel from the FRO's School of Rail. The research participants were first engaged verbally to request their participation in the research study; their responses are detailed in Table I. Further on, visits were arranged and conducted at one pilot site and the train control centre to conduct an informal focus group discussion and observations. The School of Rail was also visited to gather observational information. Documentation was viewed and collected from some of the participants, who assisted in answering the research questions and objectives.

This research used the thematic analysis process as a qualitative analytical method to identify, analyse and report on themes within the data collected [11]. The data analysis was conducted using the thematic process of creating codes from the data collected. The codes identified were then grouped into a theme that captured what was important to the research. The type of electronic train control system or OEM was the observed variable in the study to determine how the technology transfer barriers emerge based on the characteristics of the technology owner. The four OEM technologies were coded ‘A’, ‘B’, ‘C’ and ‘D’ as the nominal qualitative variables. The research validation was done through the triangulation of the various data sources to understand the research concept in depth through the research results. The results are summarised in the subsequent section.

V. RESULTS

Sixteen interview requests were made across four groups: project team members, maintenance and operations team members, training facilitators and contractors. Ten of these interview requests were accepted, yielding an overall response rate of 62.5%, with the highest participation from the project team and maintenance teams (80%). No responses were received from contractors (see Table I).

TABLE I
INTERVIEW RESPONSE RATE

Research group	Requested interviews	Accepted interviews	Response rate (%)
Project team	5	4	80
Maintenance and operations teams	5	4	80
Training facilitators	4	2	50
Contractors	1	0	0
Total	16	10	62.5

A. *Transferor descriptions*

The FRO has installed various electronic train control technologies on its rail network (see Table II). However, about 15 years ago, only Technology A was rolled out for the re-signalling of its commodity line. The other technologies (B, C and D) had only been piloted at one or two stations over the past six years. Beukman and Steyn [9] identified that technology transfer projects fail because of the lack of due diligence in the project phases, including the piloting phase. One respondent from the project team noted that the roll-out of Technology A throughout the corridor was because the project first dealt with the piloting and validation of the technology. During this phase, the key stakeholders were the technology managers responsible for validating the different technologies used by the FRO. Thereafter, the project was handed over to the execution team for implementation, testing and commissioning. In contrast, the respondent from the maintenance team for Technology C was not even aware that the FRO's technology management team had approved the technology because the pilot phase had never been formally concluded.

Two respondents from the project team had been involved in these technology transfer projects since the installation of Technology A.

The maintenance and operations teams and the training facilitators lacked experience with Technology A, but were familiar with the technologies that had been installed later. From the responses of each respondent, a few characteristics of the OEM technologies were derived. These proved to have an impact on the success or failure of the technology transfer.

Table II details these descriptive characteristics.

TABLE II
OEM CHARACTERISTICS

CHARACTERISTICS			
OEM technology	Local support/ establishment	Previous experience with FRO rail systems	Technology flexibility
Technology A	Yes	Yes	Yes
Technology B	Yes	Yes	No
Technology C	No	No	No
Technology D	Yes	Yes	Yes

A common feature highlighted by the maintenance team was the reduced amount of copper cabling and hardware required by the electronic technology, resulting in reduced incidents of theft at the stations with these electronic train control technologies installed. Additionally, the maintenance team was impressed by this technology's diagnostic tool, which allowed them to locate faults better. However, the challenge raised, especially for Technology B and C, was the restricted rights and access to the software loaded onto the hardware.

The maintenance manager of Technology C raised a concern that the electronic train control system's main CPU had crashed in 2021. Until December 2022, they had experienced trouble getting support from the FRO's technical office and the OEM. Further investigation revealed that the OEM was no longer operating in South Africa. The project team further emphasised that the project for Technology C posed serious challenges in adapting to and interfacing with the existing FRO rail systems. One of the technology transfer barriers identified by Beukman and Steyn [9] was the inappropriateness of the technology to local conditions. The OEM for Technology C had appointed a local subcontractor to bridge that gap. However, this did not deliver the required results because the FRO's project team had to bring on its experts to assist in interfacing with and adapting to local systems and conditions.

The local subcontractor's appointment allowed local skills in Technology C to be built up; however, this was missed. The transfer project for Technology C experienced both language and environmental barriers between the parties. These barriers were also identified in the research [3]. One project team respondent described the subcontractor on the project as being uncooperative and hence analysed this as a factor contributing to the barriers to technology transfer. This is supported by Chege et al. [5], who explains that collaboration between local organisations is important in technology transfer projects, as this will contribute to building local skills. The current challenge of getting support for Technology C directly indicates a need for more skills development for the technology, both at the FRO and at the local subcontractor.

The maintenance engineer currently working with Technology B identified the limited access to the building blocks or software of the technology to resolve common faults as being the most significant challenge with the new technology. Even though he had admin rights to the diagnostic tool, the common faults that required the CPU to be reprogrammed always required him to request support from the FRO's technical office or OEM, and this needed to be done formally through a procurement process. This resulted in prolonged downtime to address faults and incurred additional costs to the company to resolve commonly occurring faults. A senior engineer for technology management (the project team respondent) elaborated that the intellectual property of the technology remains that of the OEMs, and the FRO only acquires the user interface software and systems. This limits how far the team can diagnose and resolve the system faults. Further on, he mentioned that, to access the source code of the electronic train control technology, the FRO would have to develop it in-house and not just procure it from the technology OEMs. The OEMs' technologies are becoming increasingly rigid, making it hard to modify them, even to fit local conditions. The respondents who had experience with Technology A highlighted that the most significant advantage of the technology was its flexibility in modifying and programming it to local conditions. This made it easier for the FRO to test, approve and roll out the technology.

Additionally, Technology A's OEM had an excellent local basis and engineers with good experience in the South African rail industry. The FRO had adopted a set of train working rules that all its personnel and systems must adhere to. One respondent referred to it as “the bible of train operations in the FRO”. These rules inform how trains are to be operated. A good understanding of these rules is required for the FRO to accept and approve a rail system like the train control system. This OEM's knowledge made it easy for the technology to be developed for use on the FRO's rail network.

The site technician working with Technology D who was interviewed identified great support from the technology's OEM in assisting with fault-finding. This technology had been installed for almost six years and had not required the CPU to be reprogrammed, compared to the other technologies (B and C). He described the technology as being “very reliable with basically no faults on the electronic system itself”. The OEM for Technology D was well established in South Africa and had done many other projects for the FRO. Many of its developing engineers had previously worked at the FRO, emphasising the point made by Beukman and Steyn [9] that relationships should be established during the technology transfer project to mitigate barriers to technology transfer. Unfortunately, no maintenance and operations respondents for Technology A were reached during the research.

B. *Transferee descriptions*

The respondents from the project team had more and varied experiences with the different electronic train control systems (see Table III), which allowed them to better understand each technology using their previous experiences. The maintenance and operations teams only had experience with the technology in their depot. This was usually only one station as opposed to the many other stations they worked on still using the older relay-based train control.

This made it hard to develop proficiency in the system, as most of their work was still on the old technologies. The operator respondent of Technology C said she relied on asking her colleagues who had received training from the OEM during the project execution, as she had only been hired after the project had been completed. The FRO's School of Rail has not established any formal courses for the various electronic train control systems. The interview with the head facilitator for train control systems noted that most of the facilitators trained by the OEMs during the transfer projects had left the organisation.

TABLE III
EXPERIENCE OF WORKING WITH ELECTRONIC TRAIN CONTROL TECHNOLOGY

Research Group	Total Number of Respondents	Overall experience working with electronic train control (Years)				Experience with OEM technologies			
		0 – 5	6 – 10	11 – 20	20+	A	B	C	D
Project Team	4	1	1	2	0	2	4	4	3
Maintenance and operations	4	1	3	0	0	0	1	2	1
Training facilitators	2	1	1	0	0	0	1	1	1

In 2019 and 2021, the FRO had offered employees severance packages, which had resulted in several key skills in train control systems being lost across the various departments, including maintenance, operations and training. This had caused several challenges identified by the respondents:

- Loss of skills in technology management caused a delay in the formal approval or rejection of piloted technologies.
- No development of testing and training simulators in workshops and schools of rail.
- No progress made in building up internal proficiency and skills in the FRO, as people are leaving the organisation at a rapid rate.
- Training of personnel from projects, maintenance, operations and training remains reliant on projects.

It is evident that the project team respondents had gained more training. This can be attributed to their varied experience across the different electronic train control technologies. When asked how he understood a specific technology to work, one project team member responded: “I compared against another familiar system, keeping in mind that principles should be the same and questioned where there are differences.” Additionally, the project team is involved in testing and verifying the software. From that, they can understand the software build-up based on the FRO's operating rules and station designs. The maintenance team is not exposed to this, as the members are only trained to use the diagnostic tool and perform maintenance and fault-finding. The operations team is only trained on the differences in operations between the new technology and the old relay-based technology. The operations team member indicated that she only knew what her colleagues taught her on the job. She did not understand the reasoning for some of the operational actions; she only did as others told her to do.

This creates a challenge, identified by the maintenance team, that most of the faults reported to them by the operations team are because the operation was performed incorrectly. This causes an error in the system, which requires a reset or reprogramming of the CPU.

The FRO's School of Rail has not developed formal training programmes for these electronic train control systems. A visit to the School of Rail revealed that there are still major training simulators for the relay-based train control system. There have been attempts to develop a training track and simulator for Technology B, but this still needs to be completed. A few years back, the project was halted due to the contractor's liquidation. The OEMs had previously trained the training facilitators during the technology projects; however, training material had never been fully developed to allow the trainers to train technicians further.

A site visit conducted to one station with Technology B resulted in the maintenance team requesting training on the technology. Many of them needed to work on the section when the project was executed. Those who had been trained during the project in 2016 indicated that they required a refresher course.

During the site visit, there was a fault in the track vacancy detection system, and the site technicians requested technical assistance from the FRO's technical office and the OEM. The fault required the reprogramming of the addresses on the hardware after the equipment's motherboard had been replaced.

The technical office engineer and the OEM engineer could assist with the fault on-site. It was concluded that the maintenance technicians were unable to resolve the fault because they did not have access to the finalised as-built system drawings. The issuing of finalised as-built drawings is part of the handover stage in the FRO's projects, where the project team issues the drawings both on site and on the document configuration platform. The transfer of this Technology B project had not been completed, despite the project being commissioned in 2016. This revealed the challenges experienced in the project management of the FRO's projects, including technology transfer projects.

VI. DISCUSSION

The thematic data analysis conducted resulted in the identification of themes and the associated codes from the data extracts.

Training refers to how the transferee learns and understands the technology. The FRO's respondents received various types of training, including being trained formally by the OEM, self-study and on-the-job training. All the respondents received formal training from the OEM, but more was needed for the maintenance and operations teams, and training facilitators to be fully empowered to perform their work. The project team also performed self-study because of their experience with other train control technologies. The FRO's teams applied on-the-job training to further acquaint themselves with the technology. The FRO has not developed any formal training programmes for any of the technologies.

Localisation refers to the flexibility of technology to adapt to and interface with local conditions and systems. Technologies are not flexible enough to add software changes during testing, as the software remains the intellectual property of the OEM. Interfacing with the FRO's current systems challenged the OEM.

These interfacing challenges were experienced more by OEMs that did not have engineers with experience of South African railway systems. The diagnostic capability of the technology makes maintenance and fault-finding more efficient. It is hard to get warranty support after the project has been completed from OEMs not based in South Africa.

Skills retention refers to the maintenance and building up of transferee skills. The severance package offered by the FRO led to many people leaving the organisation, especially members of the technical team with administrative access to the technology software in cases requiring software upgrades. Therefore, the FRO still relies entirely on the OEM for software upgrades. The FRO does not have the internal skills to develop electronic train control systems. Skills in train control and software development are required for the FRO to develop the technology internally. These skills are currently low or close to non-existent.

Project management refers to the management and execution of technology projects. The handover to operations and maintenance is not done duly, as the projects are completed with many shortcomings that are not resolved within the guarantee and warranty periods. The outcome of the piloting phase is not communicated, nor is the maintenance team consulted during the piloting for their members' input on the technology performance. The maintenance and operations team members, and training facilitators are not involved in the project initiation. This leads to a need for their user and training requirements to be sufficiently scoped for the project.

The data analysis revealed skills retention as an additional barrier to the FRO's electronic train control systems' technology transfer. This led to the updating of the research model as depicted in Fig. 2.

A. Learning environment

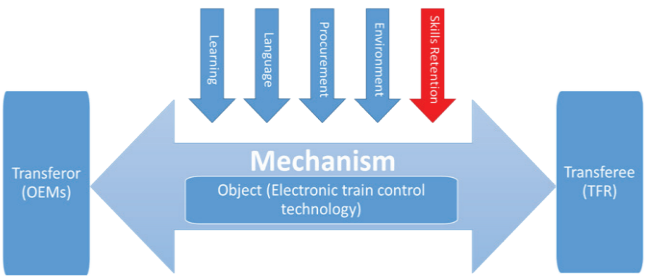

Fig. 2. Updated technology transfer framework.

All respondents who received training from the OEM were trained during the project execution. Kerr [8] suggests that this is a crucial requirement, and technical training should be done before construction and operations.

The depth of training for the maintenance and operations team members, and training facilitators was insufficient for the level of work the teams needed to carry out on the technology after the project had been completed.

This is magnified by the abandonment of developing the training curricula to further train members and develop after the project has been completed. The operations team respondent had received no formal training because she was employed after the project had been completed.

The proactive learning environment described by Omar et al. [3] was not demonstrated by the FRO, as there was no in-house formal training for these new technologies. Moreover, no agreements were in place with the OEMs to provide future training after the projects had been completed [3]. Besides these training challenges, the various FRO teams found alternate ways, such as self-study and on-the-job training, to learn the technologies. This indicates their proactiveness and willingness to learn about the technology.

B. Transferor and transferee environment

One project team respondent said: “OEM culture contributes to the level of flexibility and focuses on customer needs.” He further elaborated that OEMs sometimes ignore the important and safety-critical requirements of FRO systems. He found that this was usually the case with OEMs with little to no experience of local railway systems compared to those with local knowledge and who could adapt better to local conditions. Kerr [8] agrees with this by noting that adaptation to the local environment is crucial, especially when transferring to a country less potent than the transferor. For technology transfer to succeed, Jibat [2] emphasises the need to adapt to local conditions and integrate locally used technologies.

C. Language

The FRO's legacy train control system is outdated and not forward-compatible; therefore, new technology interfacing requires a lot of protocol inversion, which is tedious. This then makes the OEMs reluctant to pursue some changes and requirements that FRO project engineers request during testing and validation. However, the lack of flexibility of OEM technology in changing software contributes to the barriers to technology transfer. One respondent emphasised that the flexibility of the technology was directly proportional to the localisation or familiarity with South African railway systems (this was reverse-coded), indicating that the lack of local adaptation is indeed a barrier to the success of technology transfer. This was also a challenge faced by the Chinese in their high-speed railway technology transfer project, as researched by Lin et al. [12].

D. Procurement options

The test engineer (project team respondent) for Technology C's technology transfer project laughingly mentioned that on 24 December 20xx, when he was ready to commission the technology, the operators rejected the system, claiming that they had not yet been trained. The project was then suspended until January of the following year to allow the OEM to come to the control centre to train the operators. This directly links to project phasing, where projects are handed over to maintenance and operations teams while many project and system issues remain unresolved. It has been six years since Technology C was installed, and, based on its shortcomings, the maintenance manager was unaware that the technology had been fully piloted and approved by the FRO.

Beukman and Steyn [9] identified the discrepancy in measuring project performance as a cause of failure in technology transfer projects and suggested that, for piloting new technologies, the effectiveness of the pilot needs to be evaluated.

This effectiveness should be based on addressing the real needs of the beneficiaries [9].

E. Skills retention

The data analysis revealed an additional factor of skills retention that contributed to the technology transfer of the FRO's electronic train control projects. Beukman and Steyn [9] identified skills capacity building as a contributing factor to technology transfer. The lack of building the skills capacity of the beneficiaries or transferees contributed to the failure of the technology transfer process and projects [9]. The loss of the FRO's skills and personnel through severance packages created organisational and project structure gaps, as the maintenance team indicated that there was no longer an internal contact person to assist them with software upgrades. The output of technology transfer is the ability of the transferee to exploit and further develop the technology. Currently, the FRO does not have the required technical skills to develop electronic train control systems internally.

VII. Conclusions and Recommendations

Technology transfer projects have allowed for the development of emerging economies, not only through core technology, but also through the integration of socio-technological systems [8]. However, some of these transfer projects have failed due to various factors. This main goal of this research was to identify and investigate the barriers to technology transfer that contribute to the less-than-optimal operation and maintenance of the electronic train control systems installed on the FRO's rail network. The barriers identified and investigated were informed by the research framework developed from existing literature. The literature review revealed factors that influence the success of technology transfer in projects and, when not handled correctly, could pose barriers to successful technology transfer.

From the literature review and the developed research framework, the factors contributing to technology transfer are the learning environment, the transferor and transferee environment, language and procurement options. The data analysis identified barriers to the technology transfer of the FRO's electronic train control and their causes. From the analysis, the most dominant barrier was the lack of skills retention in the FRO, which led to the FRO's inability to exploit optimal operations and maintenance and further develop the technology. The dominance of skills retention in technology transfer led to the development of an updated technology transfer framework, which included skills retention as a contributing factor to the technology transfer process. Another significant finding was the project management of technology transfer on projects. The completion of various stages, such as piloting and handover, were not duly done to ensure that the beneficiaries of the technology were fully empowered to maintain and operate the technology. Another barrier identified was the adaptation to local conditions and the flexibility of the technology.

From the analysis, the extent of this barrier was greater among OEMs who did not have familiarity or experience with the FRO's railway systems and philosophies. OEMs that were well established in South African railways were more flexible in integrating and interfacing with existing FRO technologies.

These barriers to technology transfer have several effects. From the analysis, a significant effect is the continued dependence on OEMs to upgrade, fix and develop the technology. This is heightened by the loss of critical skilled engineers involved in validating and approving these technologies. This also stagnated the development of training opportunities, especially for the maintenance and operations teams. Chege et al. [5] indicated that mechanisms could be put in place to mitigate barriers to technology transfer, including measuring the effectiveness of the technology transfer, effective communication, and the documentation of processes and procedures. For the FRO, this can also be achieved by distinguishing technology transfer projects from capital or operational projects, ensuring specific guidelines to implement technology transfer projects.

The following is recommended to mitigate the barriers to technology transfer for the FRO's electronic train control projects:

- The organisation should implement a technology strategy, as discussed by Khan et al. [13]. This can result in the formation of a technology transfer office (TTO), internally or externally, at the FRO, as mentioned by Arenas and González [7], to bridge the gap between technology transfer agents.
- The transferred technology should be modular, and confinement to one supplier should be eliminated to enable better access to spares and decrease dependency on the OEM. The transferred technology is already being used internationally; therefore, most parts are manufactured overseas. The FRO needs to bring in the South African manufacturing industry, and research and academic institutions so that international technology can be developed in South Africa for the South African rail context.
- Project phases should be clearly defined, especially once the pilot phase has been concluded, and there should be clear communication of the outcome to be achieved. If decommissioning is required, it should be carried out rather than leaving the technology with operations and maintenance team members without any proper validation.
- Technology should be developed in-house by having research and development laboratories, software development skills and railway train control skills. The FRO needs to gain an appetite for long-term skills development and investment in train control, and find the means to retain and attract these critical skills.
- Simulators should be built for training and testing, which will allow OEMs to provide testing material that the FRO's School of Rail will evaluate and accredit, as well as develop assessments for future training beyond the project timelines.

From the mitigation measures recommended, the FRO, as the transferee, plays a significant role in driving the technology transfer of the electronic train control systems.

The FRO must ensure that it can build up skills internally for the exploitation and further development of the technology. It must also ensure that technology transfer projects are phased and implemented with all stakeholders involved to ensure that all the project and technology deliverables are handed over to it upon completion of the projects. The project management team must put tools in place to measure the effectiveness of the technology transfer before the FRO can fully approve and accept the technology. The OEMs, then, have the role of being well acquainted with South African railway conditions and systems so that they can better interface with existing FRO systems and build up software that adheres to the design philosophies of the FRO's train control requirements.

This research report will contribute to the body of knowledge on the technology transfer projects of railway systems, specifically those of train control systems in South Africa. The managerial implication of this research is that of informing the FRO (and other rail operators) of the barriers that affect the successful implementation of electronic train control systems on their networks. From the recommendations provided, the rail operators can find ways to adopt these in their future electronic train control projects, but may also go back to previous projects and improve on the current state.

The research was only conducted for the projects undertaken by the FRO. The passenger rail operator (PRO) has also, over the past years, embarked on projects to upgrade its train control systems to the electronic systems offered by various OEMs. The research was therefore limited to the FRO. Additionally, the data gathered could not include information from the OEMs due to a lack of responses. However, there may be other factors that contribute to the less-than-optimum operation and maintenance of the electronic train control systems installed on the FRO network. However, this research only considered technology transfer as a contributing factor to this reduced optimisation.

For future research, it is recommended that the perspective of the OEM be investigated in implementing electronic train control technology transfer for South African railway operators. The PRO's technology transfer projects can also be examined. A contrast can then be drawn between implementing a new railway line using the latest electronic technology, such as the Gautrain, how the technology transfer for that project has been done, and if similar projects can be implemented in other provinces as well. Finally, an investigation into the inclusion of a TTO can be conducted to determine its effectiveness in mitigating the identified technology transfer barriers in implementing electronic train control systems or projects.

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