Research Article

e-ISSN: 3007-5297
2025: Vol 2(2), pp 1-20. https://doi.org/10.38140/ijms-2025.vol2.2.06
Interdisciplinary Journal of Management Sciences

ERRCDF Rethinking Education 4 Inclusive Development

Modelling the Root Causes of Complexity in the South African Sawmilling Industry

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EDITORIAL INFORMATION
Received: 25 September 2025
Revised: 22 November 2025
Accepted: 23 November 2025
Published: 09 December 2025

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DOI: 10.38140/ijms-2025.vol2.2.06

Abstract: The sawmilling industry in South Africa has faced many obstacles that have severely impacted its competitiveness and sustainability. The complexity of the industry presents challenges for decision-making due to its dynamic nature. It has become more crucial than ever for decision-makers to incorporate expert facts and research into their choices. This study aimed to understand the operating environment of the sawmilling industry and model its complexity. A mixed-methods research approach was employed, involving the gathering of primary data through interviews with personnel in the sawmilling industry, as well as root-cause analysis and system dynamics modelling. Fishbone and causal loop diagrams were used to present and analyse the data. The study generated insights critical for modelling the sector's complexity, enabling an understanding of how the factors influence each other and impact decision-making in the sawmills. The industry has the potential to gain and sustain its competitiveness by focusing on the key factors affecting the complexity of operating a mill and those faced by the industry. Sawmillers can use the findings to examine their processes, identify areas for improvement, and assess potential implications. Other industry stakeholders can also utilise the results to identify ways to enhance the industry's competitiveness and inform the government's industrial policy on sawmilling in South Africa. A limitation of the study was the lack of input from representatives of informal sawmills. Future research will focus on understanding the issues affecting small-scale and informal sawmills to determine how they can be supported in contributing to the industry's sustainability.

Keywords: Complexity, root-cause analysis, operating environment, sawmilling industry, competitiveness, sustainable industries.

1. Introduction

Keeping a competitive edge is crucial for the sawmilling sector, but this has become more challenging (Björheden & Helstad, 2005). Various uncertainties present in most production environments impact production planning and management, making them more difficult (Zanjani et al., 2011). The strategic manufacturing choices made by sawmills to increase their earnings can be categorised into three primary approaches: increasing volumes to reduce fixed costs per produced unit, enhancing value-added production to raise unit earnings, and boosting productivity to lower costs per unit (Roos et al., 2001). Additionally, there is intriguing evidence that value-added strategies in the sawmill industry generally have favourable effects on profitability; however, a study of the Swedish sawmill industry revealed that some investments have resulted in significant failures despite their initial promise (Brege et al., 2010). With the rate of change accelerating—such as the establishment of new timber processors, competition from alternative materials for conventional wood uses, and pressures from new building techniques on material providers—the sawmilling sector must adapt to these emerging challenges or risk collapse (Björheden & Helstad, 2005).

How to cite this article:
Tshavhungwe, V., Oosthuizen, R., & Grobbelaar, S. (2025). Modelling the root causes of complexity in the South African sawmilling industry. *Interdisciplinary Journal of Management Sciences, 2*(2), a06. https://doi.org/10.38140/ijms-2025.vol2.2.06

Kazemi Zanjani et al. (2011) stated that the goal of production planning in sawmills is to select the optimal number of logs from various log classes and the corresponding cutting patterns to meet product requirements. They added that a backorder cost will be considered when determining whether to defer the portion of demand that cannot be met on time due to machine capacities, log inventory, and unpredictable yields. This is because log usage expenses and product inventory/backorder costs must be kept to a minimum. Non-homogeneous and unpredictable properties, such as diameter, knot quantity, and underlying defects, can be found in various logs within each class, as trees grow under uncertain natural conditions (Zanjani et al., 2010). Therefore, understanding the significance of wood quality to sawmills is crucial for comprehending price trends (Regmi et al., 2022). It should also be noted that the yield from any cutting pattern is variable (Zanjani et al., 2010).

Björheden & Helstad (2005) highlighted that the inflow of raw materials is essential to the sawmilling sector, as it determines the final product mix and, consequently, the turnover rate and pricing point. Many sawmills are seeking methods to increase the value derived from their raw materials due to environmental regulations and rising log prices, with improving volume recovery being one of the more traditional approaches (Ngobi et al., 2024). Currie et al. (2018) stated that it is more important than ever for decision-makers to incorporate insights from experts and research into their decisions. Therefore, the study aimed to gain an understanding of the operating environment of the sawmilling industry. It also sought to model the complexity of the industry to understand how dynamic factors interact and influence one another, as well as their impact on decision-making. To fulfil the objectives of the study, the following research questions were formulated:

- What factors affect the running of sawmills?
- What factors add to the sawmilling industry's complexity?
- What are the main obstacles to sawmill decision-making?
- How can the industry gain and sustain its competitiveness?

The research questions formed the basis for the semi-structured interviews.

2. Methodology

The study employed a mixed-methods approach grounded in pragmatism, involving the collection of primary data through interviews and systems thinking modelling. This approach ensured that the internal validity of the results was maintained by selecting interview participants who represented various levels of management in sawmills, thereby reducing bias in responses. The external validity of the data was ensured by verifying that the study findings would be applicable to different industry stakeholders. The study adheres to the pragmatist research approach, which acknowledges the existence of multiple variables and the idea that no single perspective can provide the complete picture (Saunders & Tosey, 2012). Pragmatist researchers assert that the practical implications of research findings are what confer their significance (Saunders & Tosey, 2012). The specific approaches followed are described in the sections below.

2.1 Data collection

Semi-structured interviews were conducted with seven senior-level personnel from sawmills in South Africa. To obtain sufficient data, it is proposed that the overall number of respondents be determined by how effectively coverage and response reliability are balanced (M. N. K. Saunders & Townsend, 2016). Seven participants were deemed sufficient to gain expert opinions on the South African sawmilling industry. Seven managers from four provinces, representing various sawmills with varying production capacities, ensured situational and operational heterogeneity within a small but diverse expert group. This is justified by Guest et al. (2006), who outlined that saturation occurred during the first twelve interviews, despite the fact that key elements for metathemes appeared as far back as the sixth interview. The interviews were conducted on Microsoft Teams, using recording and transcription. The interview transcripts were analysed using Atlas.ti. The data was also grouped manually into different themes according to the various research questions. The themes were extracted based on how well they fit the theme. The modelling approach sought causal linkages and systemic patterns.

2.2 Root-cause analysis

A root cause analysis of the complexity in the sawmilling industry was conducted using a fishbone diagram, also known as an Ishikawa diagram, developed by Mr. Kaoru Ishikawa, a Japanese quality control statistician (Bose, 2012). This diagram is frequently used in cause-and-effect analyses to identify the intricate interactions between factors contributing to a particular issue or occurrence (Coccia, 2018). In addition to ensuring the company's overall productivity and success, the use of quality management systems is crucial for raising consumer satisfaction and enhancing the standard of goods and services provided (Luca & Luca, 2019).

2.3 Systems thinking modelling

The operational environment of the global forest sector is becoming increasingly complicated and interconnected with other industries, resulting in significant structural changes (Stern et al., 2015). In various domains, system dynamics modelling has proven to be highly beneficial in assisting decision-makers in comprehending and forecasting the dynamic behaviour of intricate systems to facilitate the establishment of effective policies (Currie et al., 2018). This is because the study of system dynamics focuses on problematic behaviour over time, and causal loop diagrams help identify the underlying reasons for this behaviour (Tomoaia-Cotisel et al., 2017).

System dynamics qualitative modelling was employed because the current methods of analysis used to support evidence-based decision-making, such as statistical modelling, have limitations in explaining causality and how nonlinear processes and feedback affect complex system performance (Currie et al., 2018). The ultimate objective of qualitative modelling is to create causal loop diagrams that illustrate the interplay of dynamic aspects (Walters et al., 2016).

VENSIM was used for qualitative modelling by constructing causal loop diagrams (Khan et al., 2009; Walters et al., 2016; Martínez-Marín et al., 2020). Causal loop diagrams consist of arrows, or causal influences, between elements and pairwise element polarities that are either positive (+), indicating that an increase or decrease in one component triggers a corresponding increase or decrease in the other, or negative (−), signifying that the opposite of a beneficial impact occurs, meaning that an increase or decrease in one aspect causes a decrease or increase in the other (Walters et al., 2016). An investigation of the polarity of feedback loops, which are typically represented by an "R" for reinforcing loops or a "B" for balancing loops, can reveal the underlying causes that drive system performance (Walters et al., 2016).

2.4 Ethical Consideration

The EBIT Research Ethics Committee granted ethical clearance for the study, with the reference number EBIT/340/2024. Informed consent was obtained from all participants prior to conducting the interviews.

3. Presentation of Results

The first part of the results presented below discusses the interview responses, which demonstrate the complexity of the industry. Based on the gathered information, a cause-and-effect analysis was conducted to understand the factors influencing the competitiveness of the sawmilling industry. This was followed by system dynamics modelling using a causal loop diagram to illustrate the complexities within the industry.

3.1 Feedback from the interviews

The answers to the interview questions are presented under the sub-themes below. Each sub-theme relates to research questions.

3.1.1 Job functions of the interviewees

To understand the roles and responsibilities, as well as the decisions made by the study participants in their respective roles, participants were asked to introduce themselves according to their primary responsibilities. Interviewee 1 indicated that they are responsible for looking at the production figures for the entire plant and analysing them. Interviewee 2 stated that their role is to oversee production, ensuring they have sufficient logs for the sawmill, achieve the desired throughput in the wet mill, and manage both primary and secondary production processes. Interviewee 3 indicated that they manage the entire operation from receiving logs to the final dispatch of the products.

Interviewee 4 indicated that their primary responsibility is planning day-to-day activities and checking the availability of materials to cut. They noted that in the wet mill, they check the available stock, compare it with the order, and determine what the market wants, which usually informs the day's cutting pattern. Interviewee 5 indicated that they oversee the company's business function and strategic objectives. Interviewee 6 indicated that a typical day for them begins with receiving feedback on the previous day's production, inspecting the production line for potential bottlenecks, and planning the next day's production. Interviewee 7 stated that they oversee the production. They added that the technical aspect of their job involves a lot of record-keeping, making on-point decisions, and analysing production and planning. Table 1 presents the various roles of the interviewees, as well as the region where they work at the sawmill.

Table 1: *The job profiles of the interview respondents*

#	Role	Mill type/size	Region/Province
Interviewee 1	Production manager	Medium/Large	Mpumalanga
Interviewee 2	Production Manager	Medium/Large	Limpopo
Interviewee 3	Sawmill manager	Medium/Large	Eastern Cape
Interviewee 4	Section manager	Medium/Large	Limpopo
Interviewee 5	Business manager	Medium/ Large	Limpopo
Interviewee 6	Production manager	Medium/ Large	Mpumalanga
Interviewee 7	Section manager	Medium/Large	KwaZulu-Natal

The interviewees represented a diverse range of roles across various regions in South Africa. Several of them mentioned having worked in different roles and at sawmills of varying sizes throughout their careers, including both structural and non-structural timber sawmills. This diversity was beneficial during the interviews, as it allowed for a variety of perspectives to be brought to the discussions.

3.1.2 Challenges with decision-making in a sawmilling environment

Interviewee 1 highlighted that the biggest decision-making challenge was the "unknown variables" affecting their production. They indicated that unknown or unforeseeable events are a challenge and that one must mitigate them as best as possible by implementing contingency plans. Similarly, Interviewee 3 highlighted the markets as the biggest challenge, as markets are unpredictable.

Interviewee 2 highlighted the limitations of their technology as a significant challenge. They indicated that the industry didn't take the opportunity to invest in new technology and that they are still stuck with outdated machinery. They also mentioned that another challenge is the low prices. They emphasised that obsolete equipment and technology slow production, and the production costs keep rising above what can be produced. Interviewee 4 stated that the biggest challenge for them is the supply of raw materials, as inconsistent and insufficient supplies can necessitate production halts and changes to the production plan.

Interviewee 6 discussed the weather patterns in the area surrounding the mill. They said that rain affects the delivery of logs to the mill. They indicated that the inconsistency of log supply affects planning if you do not know the log mix coming to the sawmill. They said they can use historical data to see what they can expect regarding logs, but it is not always accurate. Interviewee 5said that the challenge is the marginal environment in which they work. They mentioned that you cannot just spend money fixing a problem, but you have to find other ways to solve issues. They indicated that a lot of effort must be put into generating revenue for the company.

The interviewees highlighted aspects they consider the most significant challenges with decision-making in the sawmill. From these responses, it was evident that interviewees often make different decisions or adapt their strategy or plan for the day based on what is happening around them.

3.1.3 Short-term and long-term decisions at the sawmill

The raw material (timber) used in sawmilling is heterogeneous, and the sawmilling environment is dynamic. To understand the nature of decisions in the sawmills, the interviewees were asked about the long-term and short-term decisions they make.

Interviewee 2 stated that all decisions affect both long-term and short-term planning, as something short-term can impact the long term. They indicated that even a one-day loss of production impacts throughput in the long term. Similarly, Interviewee 1 noted that although short-term plans are constantly changing, one must still keep them aligned with the monthly and financial year plans. They provided an example of how, to deal with the changes, they might have to bring forward their plans for next week, moving the current plan to the following week and factoring in their raw materials to ensure they can still meet their targets. They emphasised the need for flexibility, as they would fail to achieve anything without it.

Interviewee 3 indicated that in the day-to-day decision-making process, it is easy to determine which materials they can obtain from the harvesting teams and which products they want to produce to meet orders. However, in the long term, it is challenging to predict what the market will look like and which compartments will be harvested from forestry operations.

Interviewee 6 mentioned that short-term decisions are those that constantly change, such as the product mix, which depends on market demand. They added that the product flow, the products they produce, and their quantities are short-term decisions that are constantly evolving. In terms of long-term decisions, they highlighted machinery or process changes, such as transitioning from solids to finger-jointed materials or vice versa; modifying processes and implementing a second shift, which would necessitate hiring additional personnel; and rotation ages that affect log supply, which also impacts the reliability of historical data.

Interviewee 4 mentioned checking the market and customer needs for short-term decisions. They indicated that in most cases, they cut for a truck, that is, make-to-order. They said most sawmills adopt this principle to avoid excessive stockpiling in the warehouse. Regarding long-term decisions, they indicated that these include reviewing the staff complement and verifying that they have the right personnel to perform the job. They further expressed that the market constantly fluctuates, but it is essential to have the right people who will do the work that needs to be done.

Interviewee 7 indicated that they have more control over short-term decisions, as long-term choices are more about the company providing a strategy. They highlighted that there is a significant amount of collaboration required in decision-making; sometimes, one cannot just decide but needs to "discuss, discuss, discuss, and discuss". Once a decision is made, it is vital to communicate and inform everyone of that decision several times.

Interviewee 5 indicated that the business's daily operations occur in a constantly changing environment, including markets, customers, access to raw materials, and supply chain logistics. Long-term decision-making refers to when one can replace or install new equipment.

From these responses, the takeaway is that the markets influence many decisions in the sawmill. All the responses highlight the dynamic nature of the sawmilling environment and the necessity for flexibility in decision-making. The long-term and short-term decisions discussed above are summarised in Figure 1.

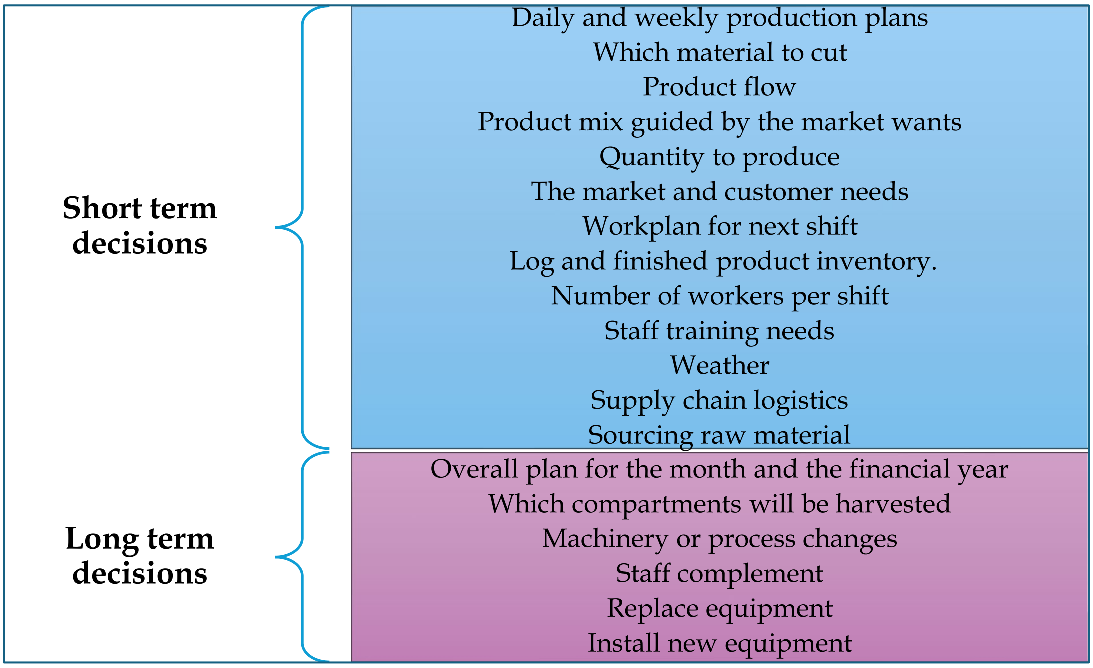

Figure 1: *Summary of the short-term and long-term decisions made in sawmilling*

3.1.4 South African sawmilling industry competitiveness

The interviewees were asked if they thought the sawmilling industry in South Africa is competitive. Interviewee 4 responded that the answer can vary, but they do not think the industry is competitive. They explained that, upon examining most of their competitors, i.e., plastic and steel manufacturers, they found that these companies could produce products that the sawmilling industry could make with timber; they create products that are simpler and cheaper. They provided an example of customers buying ceilings who will most likely choose polyvinyl chloride (PVC) board over timber products because they are more affordable and appealing.

Interviewee 6 stated that the dwindling log supply, particularly in the Western Cape, has affected the supply of logs to sawmills, which in turn has impacted the region's industry competitiveness. They added that, generally, forestry and sawmills remain competitive due to the balance of supply and demand. They also mentioned competitiveness in certain aspects of the industry. For example, while log prices are not competitive, the finished goods market is competitive. They indicated that many new entrants are entering the market, dumping products at low prices because their production costs are minimal, which creates problems for established mills, as they sometimes do not receive adequate value for their products. New entrants will always want to come in at a lower price due to their lower overheads. This is also because most smaller mills purchase non-FSC (Forest Stewardship Council) certified logs to meet market demand. They noted these factors contribute to the industry's competitiveness. They emphasised that if a mill produces the right volume and quality at the lowest possible price, it will always be competitive in the sawmilling industry. However, larger sawmills have significantly higher operational costs (including employee salaries, electricity, and transportation) compared to smaller sawmills, which affects their competitiveness.

Interviewee 5 stated that the industry is not competitive on a broad scale, but it also depends on what it is being compared to. They indicated that the South African sawmilling industry is not competitive internationally, noting that the local industry cannot produce at the same levels as international sawmills. They remarked that if we do not factor in the support and subsidies received by international sawmills, it can be concluded that South African sawmills are not competitive in the global market. Regarding South African competitiveness, they acknowledged that there are sawmills they consider competitive, but the majority are privately owned. They explained that as soon as sawmills operate in the corporate space, they become significantly less competitive, as it primarily boils down to the cost of production. Similarly, Interviewee 2 expressed that the sawmilling industry is not competitive. They indicated that we need to ask ourselves, when we say "competitive", compared to what? They added that the sector must compare itself with international standards, i.e., overseas sawmills. They further expressed that African sawmills have been neglected for far too long, and there is great potential.

Interviewee 7 stated that the competitiveness of the South African sawmill industry is being affected by competition, resulting in many sawmills closing, with more expected to follow. They added that the closure of sawmills is partly due to the economic market conditions in South Africa. They noted that the South African market has declined since the COVID pandemic, which was a considerable pause, and the economy took a slight dip. They highlighted that the sawmill industry typically declines when the construction industry slows in South Africa. Contrary to others, Interviewee 3 stated that the industry is competitive with other sawmills outside of South Africa, as we design our machines to be flexible enough to cut any form of logs. They acknowledged that there is still a problem within the South African sawmilling industry, where certain sawmills sell their products at lower prices because they obtain logs more affordably, which creates issues for those who cannot afford to underprice their products. Interviewee 1 remarked that the local situation is difficult to assess because the sawmill industry is small in South Africa, and the market is not massive. They added that there are large companies that dominate specific areas within this small industry, depending on the product.

3.1.5 Factors leading to complexity in the industry

Interviewees were asked what contributes to the complexity of the sawmilling industry. According to **Interviewee 6**, sawmilling and forestry are complex due to the industry's exposure to elements such as forest fires, which impact the ability to plan. They said it is thus vital to grasp the whole process, not just sawmilling, but also what the market is doing after you have produced the products and what the supplier is harvesting. They added that in terms of supply, one must understand the complexity of what happens on the supply side, as forestry is a long-term investment. Interviewee 6 further expressed that this complexity will depend on whether you are a small or large sawmill, because some small sawmills operate with a simple structure and a single machine, sometimes employing underpaid employees, versus large sawmills with numerous expenses and a larger workforce.

Interviewee 2 stated that the complexity lies in the fact that the industry is not well-regulated; it is not synchronised. They mentioned that it is simple to enter the sawmilling sector, as there is no requirement to verify that new entrants are following the industry's good practices. **Interviewee 7**, on the other hand, stated that complexity depends on one's perspective. They noted that the basic scenarios do not change; it just depends on how one wants to tackle them. They further expressed that the scope is merely expanding; however, most of the challenges that existed 20 years ago are still present today.

Interviewee 4 said that the complexity depends on the availability of resources. They supported their statement by saying that if the resources are good, the machinery is good, and if the people working are skilled, then there is no need to stress because those individuals know what they are supposed to do. Additionally, they stated that if the raw materials received are of good quality, it reduces the complexity in sawmill operations. **Interviewee 5** stated that it primarily boils down to the cost of production. If you are an owner-operator, you operate under a different cost model than a corporate operator, as the latter has many additional costs that do not necessarily yield value. Figure 2 summarises the main aspects discussed by the respondents.

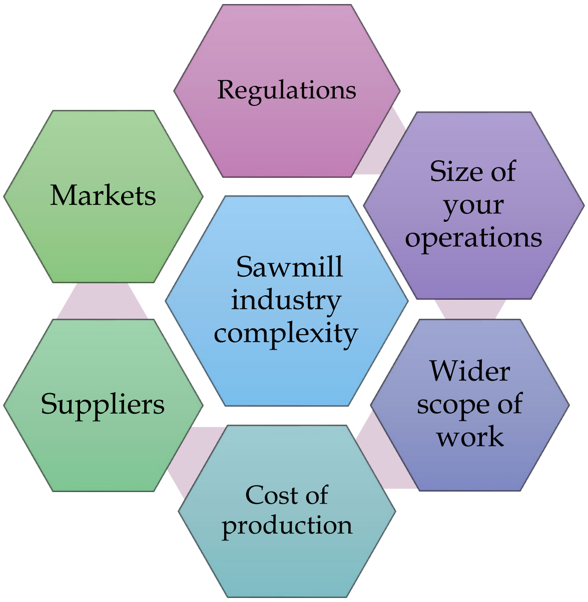

Figure 2: *Aspects contributing to sawmilling industry complexity*

3.1.6 The factors affecting the running of mills

Interviewee 1indicated that the raw material has a considerable effect due to stringent specifications. For instance, if an eccentrically shaped log is received, it cannot be processed because the equipment cannot handle a log of that size. They added that this necessitates thorough assessments of incoming loads to ensure they meet the specifications provided to their suppliers, in this case, the foresters or other log suppliers. They emphasised that quality is a significant factor, as it also influences recovery. Furthermore, they noted that brand reputation can affect sawmill sales.

Interviewee 2stated that there are more logs in South Africa than the processing capacity can handle. They expressed that there is great potential in introducing new technology and building more sawmills. They indicated that sawmills are closing because they cannot afford the necessary technology, and production and labour costs are too high. They further suggested that most sawmills could remain operational through investment in new technology and access to funding. They added that benchmarking bodies, such as Crickmay, which perform intermill comparisons, are helpful for sawmills because they rely on measurements; if you cannot measure something, you won't know how you compare to benchmarks. They indicated that most sawmills are aware of their challenges and their current performance levels.

Interviewee 6 mentioned that sometimes sawmills run at a loss if the forestry part of the business is profitable. However, they also emphasised that sawmills cannot operate without a log supply. They provided an example from the Western Cape, where the government decided not to plant additional trees, significantly impacting log supply and production volumes.

Interviewee 7 stated that most customers typically purchase timber from the sawmill that offers the lowest price rather than one based on quality. They highlighted how Bushmills, which usually doesn't have the overhead costs that larger sawmills have, can sell ungraded, wet, and untreated timber at the same price that formal sawmills charge for graded timber. As a result, larger sawmills will try to combat this by exporting most of their products.

3.2 Cause-and-effect analysis of the complexity in the sawmilling industry

A fishbone diagram was constructed to identify and categorise the root causes of complexity in a sawmilling environment. The factors contributing to this complexity are illustrated in the fishbone diagram in Figure 3. The various root causes were grouped under the categories of people, environment, machine, methods, measurements, and materials. The different nodes in the diagram demonstrate that multiple aspects coexist in the sawmill industry, each presenting itself differently but collectively contributing to the sector's complexity. This creates challenges in decision-making, as numerous factors must be considered in the process.

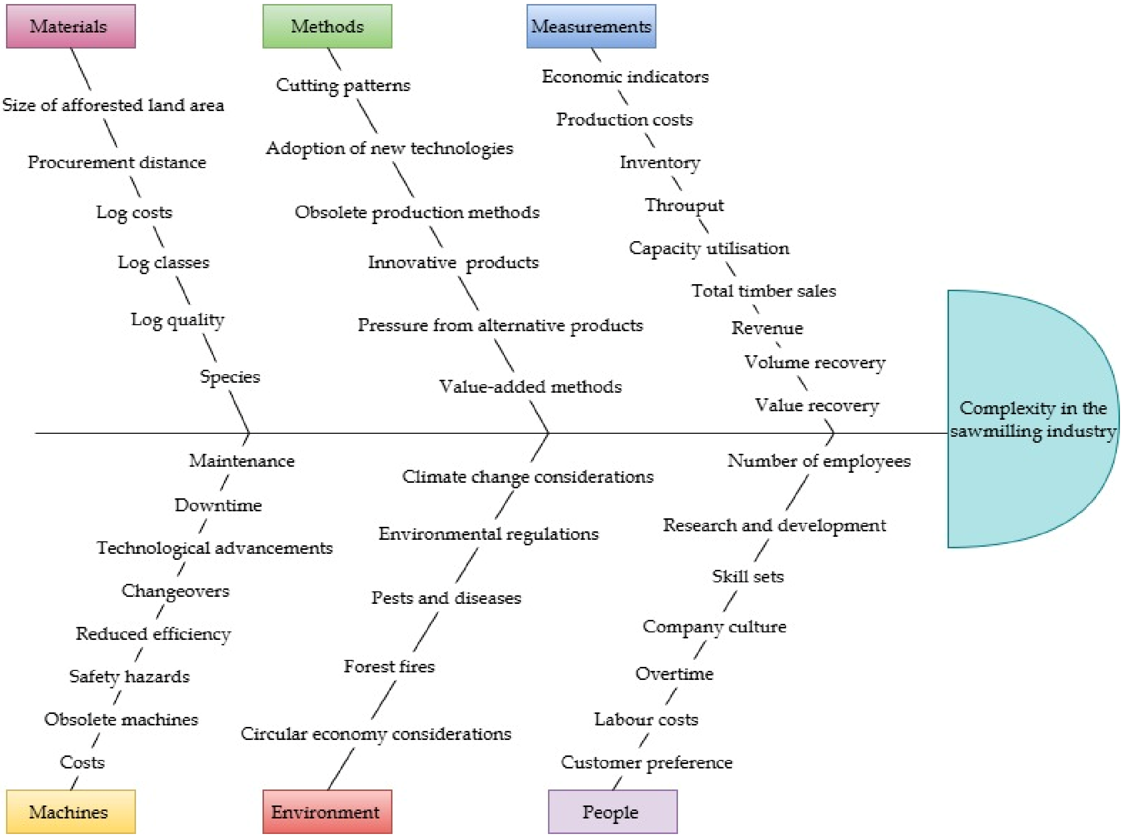

Figure 3 *Categories of the factors leading to complexity in the sawmilling industry*

Examining logs, which fall under the materials category, it was noted from the interview responses that logs will impact measurements such as volume, value recovery, and timber sales. Under methods, log classes will influence the cutting patterns and the ability to produce innovative timber products. Environmental factors, such as forest fires, pests, diseases, and environmental considerations, will impact the materials in terms of the size of the afforested land area, the species planted, and the availability of logs for processing. The methods, machines, and people all directly influence each other because production methods affect the number of employees required, the machines used require specific skill sets from the operators, and customer preferences inform the cutting patterns, value-added methods, and pressure from alternative products. Sawmill measurements, such as production costs, depend on the sawmill's machines, methods, materials, and people factors.

3.3 Modelling industry complexity using systems thinking modelling

The interview findings and recommendations were used to update and expand the causal loop diagram in Figure 5, which was developed from a literature review. The definitions of terms and polarity are shown in Table 2. The updated causal loop diagram, highlighting the complexity in the sawmilling industry, is shown in Figure 6. Insights from interviewees were incorporated, resulting in this revised diagram. Various factors that contribute to the complexity and impact the competitiveness of the sawmilling industry are modelled using the causal loop diagram. Discussions with the interviewees emphasised the importance of capital in sawmill operations and the need to reduce production costs. Another key contribution was the differentiation between value and volume recovery. The sections of the diagram are further broken down to explain its narrative in Figures 7 to 13.

Table 2: *definition of variable used for qualitative modelling*

Variable	Operational definition	Assumed polarity	Qualitative weighting
Available wood resources	The logs to process at the sawmill	Positive	High – directly affects throughput rate and log quality
Available capital	The money available to spend at the sawmill	Positive	Very high – directly affects Production methods investments, Production capacity investment, skilled labour, number of employees and available wood resources
Customers	Customers who purchase products or services from an enterprise	Positive	High – Directly influences product demand
Higher-grade timber	The recovered grades from the processed logs	Negative	High- directly affects the product mix
Labour costs	The overall costs a business incurs for its personnel	Negative	Medium – influences production costs
Log quality	The properties of a log that define its usefulness and value	Positive	High – influences value recovery and timber grades quantity
Maintenance costs	The costs incurred to maintain a resource or system in optimal condition encompass both routine maintenance and essential repairs.	Negative	Medium – influences overhead costs
Number of employees	The overall number of individuals working for a firm	Negative	Medium – influences the number of employees
Overhead costs	The recurring cost of running an enterprise	Negative	Medium – influences production costs

	that is not immediately tied to creating the products.		
Production capacity investment	Investment in a processing facility's maximum output, expressed in terms of end products, over a specified period.	Positive	High – Influences the throughput rate and the available capital
Production methods investments	Investment into the methods and technologies used to convert raw resources, labour, and capital into completed products	Positive	High – Influences product mix, utilities, maintenance costs, labour costs and the available capital
Product demand	The need of customers to buy products and their willingness to spend a certain amount at a specific moment.	Positive	High – directly affects the product mix and volume recovered
Product mix	A firm's whole line of products	Positive	Medium – Total timber sales
Production costs	The overall costs that a firm incurs when producing a product	Negative	High – Influences available costs
Revenue generated	Income generated from any firm's activity that directly aids in creating profits or sales	Positive	High- influences available capital
Skilled labour	Employees who have the skills to carry out the tasks	Positive	Medium – influences value recovery
Timber grades quantity	Wood classification according to its quality, strength, and appearance for certain uses	Positive	High - Affects value recovery and volume recovery
Total timber sales	The amount of timber sold in the sawmills	Positive	Medium – influences revenues generated
Technological advancements	The development and improvement of instruments, infrastructure, and techniques to promote effectiveness, output, and the overall standard	Positive	Medium – improves production methods
Throughput rate	The rate at which a process generates outcomes	Positive	High – increases the production costs and volume recovery

Utilities	The essential services that a company requires to run, such as water and electricity	Negative	Medium – increases the overhead costs
Volume recovery	The quantity of useful timber obtained from a log	Positive	Medium – increases product mix
Value recovery	Maximising the market value of timber products from a given quantity of logs.	Positive	High – influences revenue generated and higher-grade timbers

Table 1 shows the definition of the variables used to qualitatively model the complexity in the sawmill industry. The figure key for interpreting the causal loop diagrams is shown in Figure 4.

B = Balancing loop
R = Reinforcing loop
≠ = Time delay

Figure 4: *Figure key for interpreting the causal loop diagrams*

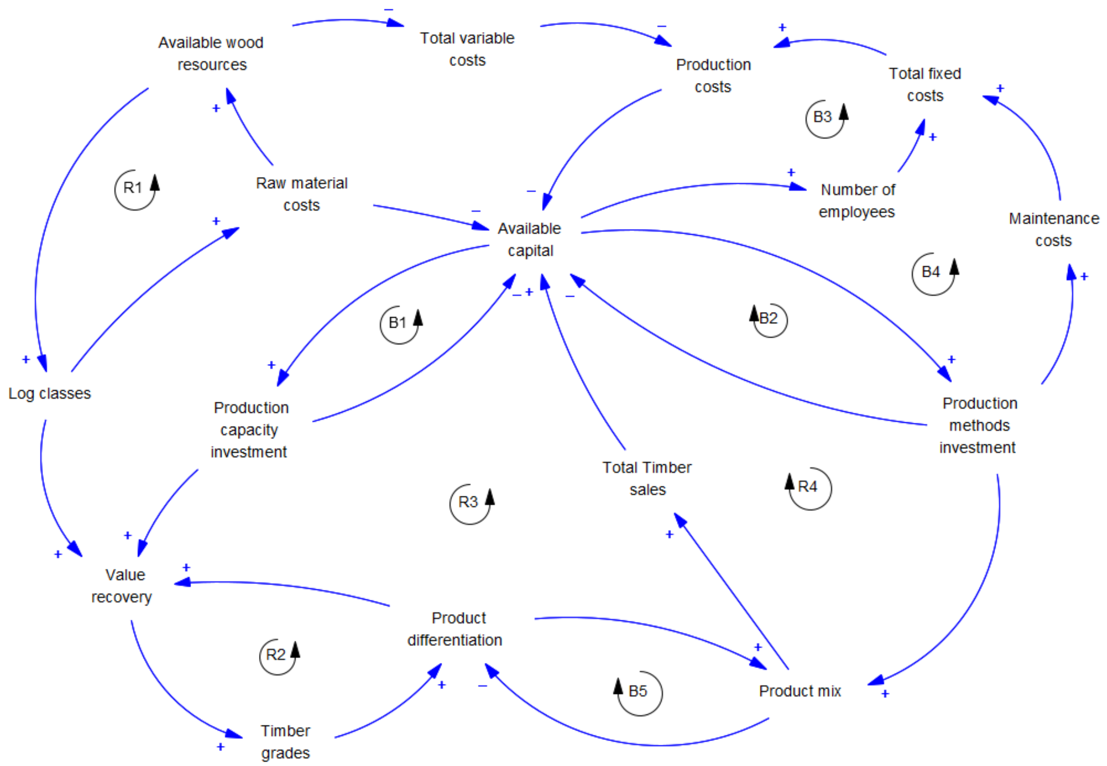

Figure 5: *Causal loop diagram developed from literature studies. Source: "author and year"*

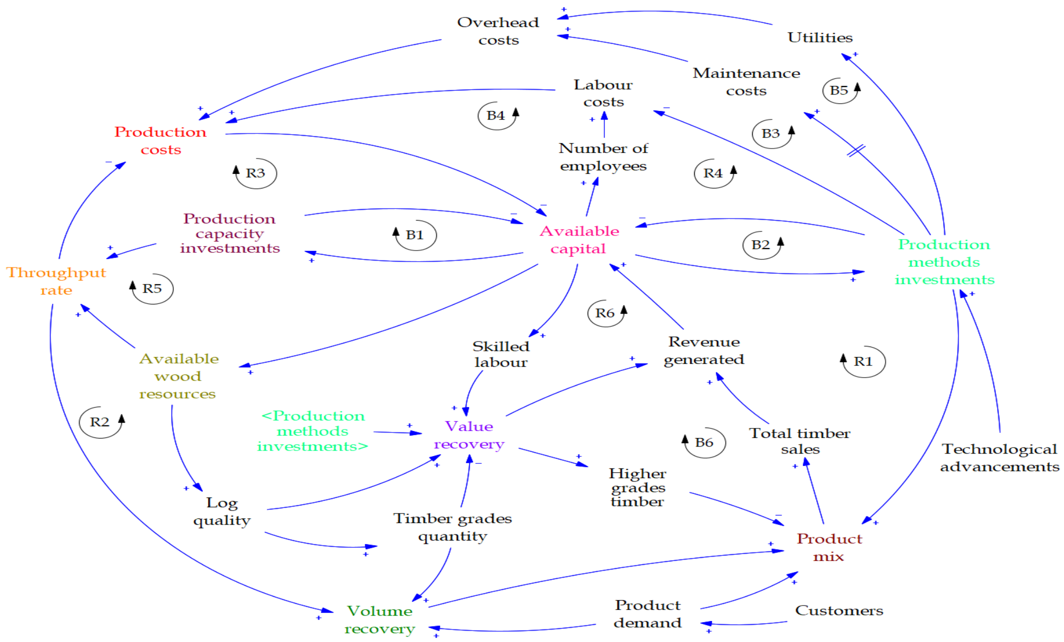

***Figure 6**: Causal loop diagram of the sawmilling operating environment*

The larger diagram in Figure 5 has been broken down into smaller loops to highlight the connections between variables. Each loop indicates whether the decision path is balancing (B) or reinforcing (R). Figure 6 illustrates how available capital in sawmills enables investment in both production capacity and production methods. However, the counter effect of these investments is that available capital may be reduced once money is spent on increasing capacity and introducing or updating production methods. Investing in production methods can reduce labour costs, while investing in production capacity can increase the throughput rate and potentially lower production costs. High production costs tend to diminish the available capital in the sawmills.

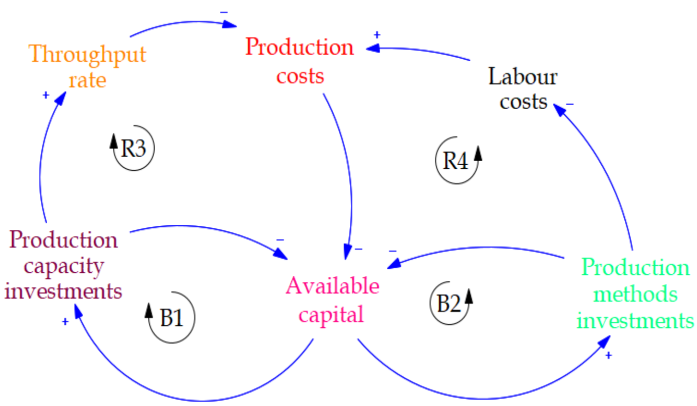

***Figure 7**: sawmill Investments loops*

Figure 7 illustrates the options for utilising available capital for investments in production methods or for increasing the number of employees. An investment in production methods may result in increased maintenance costs and higher utility bills (e.g., electricity) over time, leading to higher overhead costs. Increasing the number of employees could also lead to higher labour costs. Either decision could potentially increase production costs and reduce the available capital at the sawmill.

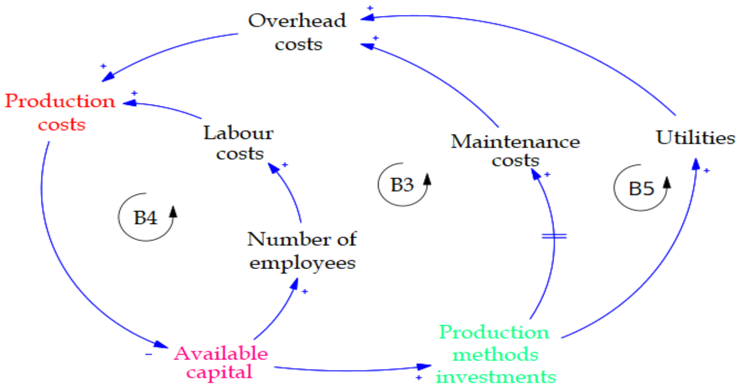

Figure 8: *Production costs loops*

Figure 8 illustrates how capital investment in production methods can enhance the product mix produced, enabling more timber sales, which in turn can increase both the revenue generated and the available capital in the sawmill.

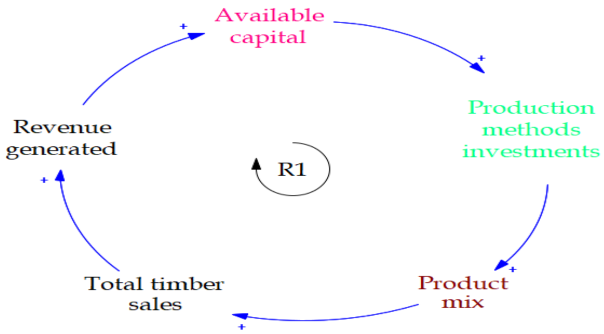

Figure 9: *Increasing product mix loop*

Figure 9 illustrates how hiring skilled labour (e.g., machine operators) may increase the value recovery of the timber produced, thereby potentially increasing the revenue generated and available capital in the sawmill.

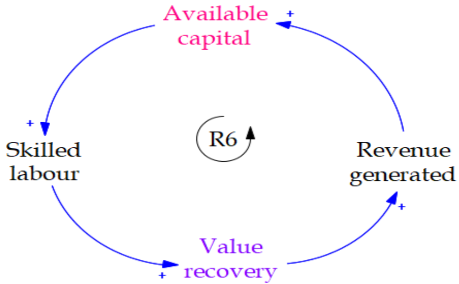

Figure 10: *Hiring of skilled labour loop*

Figure 10 illustrates how the availability of capital in the sawmill enables sawmills to purchase logs, thereby ensuring they have sufficient wood resources, which may increase the throughput rate and reduce production costs.

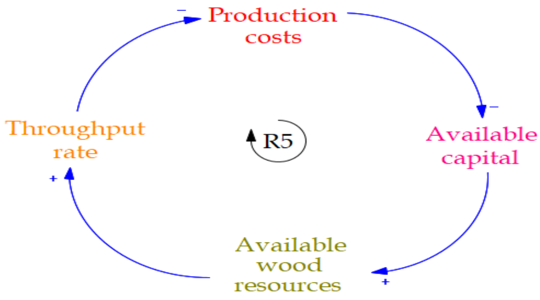

Figure 11: *Available wood resources loop*

Figure 11 illustrates how investing in production capacity could increase the throughput rate, thereby possibly increasing the volume recovered in the mill. The recovered volume might result in an increased product mix, higher total timber sales, and increased revenue and available capital.

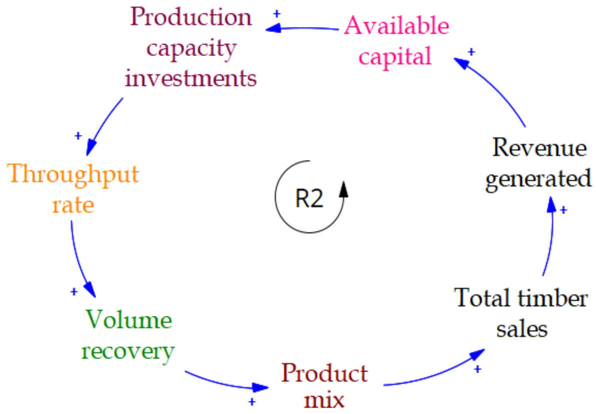

Figure 12: *Volume recovery loop*

12 illustrates how capital investment in production methods (e.g., optimising scanners) can increase the value recovered from the logs, resulting in higher-grade timber. The production of higher-grade timber could reduce the product mix produced. The higher value of timber may increase the revenue generated from total timber sales, thereby possibly increasing the available capital.

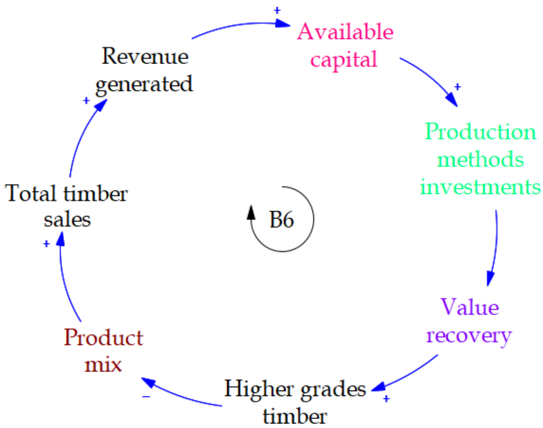

Figure 13: *Value recovery loop*

A consolidated summary of the loops is shown in Table 3.

Table 3 consolidated table of the decision paths

Causal loops	Decision path
B1	Available capital → Production capacity investments → Available capital
B2	Available capital → Production methods investments → Available capital
R3	Available capital → Production capacity investments → Throughput rate → Production costs → Available capital
R4	Available capital → Production methods investments → Labour costs → Production costs → Available capital
B4	Available capital → Number of employees → Labour costs → Production costs → Available capital
B3	Available capital → Production methods investments → Maintenance costs → Overhead costs → Production costs → Available capital
B5	Available capital → Production methods investments → Utilities → Overhead costs → Production costs → Available capital
R1	Available capital → Production methods investments → Product mix → Total timber sales → Revenue generated → Available capital
R6	Available capital → Skilled labour →Value recovery → Revenue generated → Available capital
R5	Available capital → Available wood resources → Throughput rate → Production costs → Available capital
R2	Available capital → Production capacity investments → Throughput rate → Volume recovery → Product mix → Total timber sales → Revenue generated → Available capital
B6	Available capital → Production methods investments → Value recovery → Higher grades timber → Product mix → Total timber sales → Revenue generated → Available capital

The causal loop diagrams illustrate that different decision-making paths result in varied outcomes, depending on the chosen route.

4. Discussion of Findings

The study's results addressed the research questions by examining the factors affecting sawmills' operations, the complexity of the sawmilling environment, and the obstacles to sawmill decision-making, paving the way for the South African sawmilling industry to gain and sustain its competitiveness. The interviews conducted with personnel working in various sawmills provided valuable insights into the operating environment of the South African sawmilling industry. These insights were crucial in modelling the sector's complexity to understand how the factors influence each other and impact decision-making. From the interviews, it was observed that the various roles performed by the interviewees require them to make several short- and long-term decisions. These short-term decisions are often changing and contribute to the complexity of the operations. This is supported by Bose (2012), who outlined that business operations are undoubtedly complex, and increasingly so in this highly competitive environment. Björheden and Helstad (2005) indicated that the distinguishing traits defining a profitable business are agility, awareness, responsiveness, and the capacity to handle complexity.

Using the cause-and-effect diagram ensured that the factors contributing to complexity in the sawmilling industry were categorised and evaluated separately and collectively. High production costs in the sawmills can significantly impact the mill's ability to invest in other value-adding projects that can enhance its productivity. This is further emphasised by Haimes (2012), who mentioned that the interdependent, interrelated components have various roles, activities, and stakeholders, making up complex systems. For example, in their study, Regmi et al. (2022) indicated that the total number of staff, sawlog dimension, procurement distance, and sawlog grade all positively impacted sawmills' inclination to pay more for higher quality sawtimber. In contrast, processing capacity and years of operation had an adverse impact.

Measurements are crucial in the sawmill environment, as they enable decision-makers to make more informed choices. Roos et al. (2001) mentioned that since the economic indicators consider variable expenses and earnings, they are currently the most effective performance indicators. One of these critical measurements is quality, which is seen as a vital component of advancement in the new business model that has been created by increased competition and the capture of sales markets (Luca and Luca, 2019).

This study's use of causal loop diagrams ensured that the relationships between variables were considered, providing more informed decision-making. This is because certain decisions may seem reasonable independently; however, they can still have unfavourable effects on the system in the long run or prevent other crucial activities from being carried through. For example, Ngobi et al. (2024) highlighted that modifications to overall production tactics may result in reduced volume recovery but would always result in higher value. Such information is essential to understand, as sawmillers must often decide whether to prioritise value or volume recovery, as either decision will impact the product mix produced in the sawmills and thus the revenue generated from the sold timber. Additionally, adding more production methods to the basic sawn wood production process and integrating and controlling the downstream processes to expand the product range are examples of value-added methods intended to increase profit margins (Brege et al., 2010).

The availability of capital in the sawmill can lead to management decisions regarding whether to invest in production methods or allocate funds to hiring more employees. Either decision can yield positive or negative results for the company. In this regard, Abdallah et al. (2013) found that the age of machinery had a detrimental impact on sawmill performance. In contrast, the owners' or managers' education and expertise, collaboration, and the sawmill's capacity had beneficial effects. This means there is a need to invest in skill sets, production methods, and production capacity, provided sufficient capital is available. To address the issue of skill sets, Abdallah et al. (2013) mentioned that sawmill owners must try to hire qualified workers and experienced sawmill managers or implement on-the-job training programmes.

The study highlighted the need to make more informed decisions that will benefit the sawmill and increase its capital. In their study, Johansson (2004) outlined how, in response to the demands of changing organisational structures and market conditions, several Swedish sawmills have lately created product-costing systems for lumber products, where market organisations have evolved from decentralised ones, in which a salesperson oversaw a single sawmill's sales, to centralised ones, in which the salesperson oversees particular markets or clients using goods from multiple mills. This can be a solution for sawmills in close proximity to each other, focusing on value recovery rather than product mix, as different sawmills can concentrate on specific products. The decision to invest in either production capacity or methods can impact the amount of money the company has to allocate to other business areas. Björheden and Helstad (2005) suggested that perhaps the answer lies in customised products and services. However, the new goods also require more managerial and technical expertise, as well as additional capital, effective production control, rigorous research and development, product testing, and sales efforts. According to the interview results, the availability of wood is a factor that affects the operation of sawmills. The causal loop diagrams highlighted the importance of available capital in running sawmills. The main obstacle to sawmill decision-making was observed through the different decision pathways shown by the causal loop diagrams and their causal effects. By identifying the more suitable decisions and examining the factors presented in the study, the South African sawmilling industry can enhance and sustain its competitiveness.

5. Conclusions and Recommendations

The sawmill industry in South Africa has the potential to gain and sustain its competitiveness by focusing on the key factors that affect the complexity of operating a sawmill, as well as those faced by the industry. This study mapped out the complexity of the sawmill industry as outlined in the interview responses. The use of mapping tools, such as the cause-and-effect diagram and causal loop diagrams, ensured that the sector's complexity was mapped and analysed in a way that shows the relationships between the various factors of the industry, as well as their feedback loops. Sawmillers can use these figures to examine their processes and identify areas for improvement. The overall study results and views from the sawmillers can also be used by other industry stakeholders to identify ways to enhance the industry's competitiveness and by the government to inform industrial policy on sawmilling in South Africa.

The study contributes to the body of knowledge by providing a visual representation of the various factors that lead to complexity in decision-making within the sawmilling environment. Limitations of the study included the lack of input from representatives of informal sawmills in South Africa, as they might have provided a different perspective on understanding the challenges and factors affecting these informal sawmills. Future research will focus on understanding the issues affecting small-scale and informal sawmills to determine how they can be assisted in contributing to the industry's sustainability, particularly since some of the challenges raised in the interviews highlighted the differences between the operating conditions of established and informal sawmills.

6. Declarations

Author Contributions: Conceptualisation (V.T., R.O. & S.G.); Literature review (V.T.); methodology (V.T. & R.O.); software (N/A.); validation (V.T., R.O. & S.G.); formal analysis (V.T.); investigation (V.T.); data curation (V.T.); drafting and preparation (V.T.); review and editing (R.O. & S.G.); supervision (R.O. & S.G.); project administration (V.T.& S.G.); funding acquisition (V.T.). All authors have read and approved the published version of the article.

Funding: This research was sponsored by the National Research Foundation of South Africa (Grant Numbers 128910) and the DHET-nGAP funding.

Acknowledgements: We thank Sawmilling South Africa for the assistance in reaching out to study participants.

Conflicts of Interest: The author(s) declare no conflict of interest.

Data Availability Statement: All relevant data generated or analysed during this study are included in the manuscript and its supplementary materials. Additional details on data processing methods and analyses are available in the appendix.

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