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**Enhancing Textile Cone Counting Efficiency Using
Figurative Numbers and Desktop-Based Solutions:
A Systems Approach**

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ABSTRACT:

Manual cone counting in textile factories is time-consuming and error-prone, which negatively affects inventory accuracy, shift transitions, and overall operational efficiency. This study addresses that problem by developing a desktop-based cone counting application using figurative numbers, specifically triangular numbers, to model stacking patterns and automate the counting process. The aim is to reduce human error, improve consistency, and enhance digital inventory tracking in resource-constrained manufacturing environments. The research question guiding this work was: *How can figurative numbers and a desktop-based application optimize the cone counting and tracking process in textile production, minimizing human error and enhancing operational efficiency?*

The study followed a design science research methodology to design, build, and evaluate the solution. The application was developed using Python's Tkinter library, incorporating Lean Six Sigma principles, Urdu language support, and Excel-based data logging to meet the needs of non-technical users. Field tests conducted in a textile plant in Pakistan demonstrated that the application reduced cone count errors by over 95% with standard deviation dropping from 68.59 to 2.83 and saved an average of 17.25 minutes per production shift. Statistical analysis, including paired t-tests and confidence intervals, confirmed the significance of these improvements.

This study illustrates how mathematical modelling and human-centric interface design can modernize traditional inventory practices in textile manufacturing. It bridges the gap between number theory and industrial systems design by showing how abstract mathematical principles can solve practical challenges.

KEYWORDS: Figurative numbers, process optimization, desktop application, textile industry automation, Lean Six Sigma, inventory management

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Abbreviation

AI	Artificial Intelligence
CI	Confidence Interval
DMAIC	Define, Measure, Analyze, Improve, Control
DSR	Design Science Research
ERD	Entity-Relationship Diagram
FK	Foreign Key
GUI	Graphical User Interface
HCI	Human-Computer Interaction
JSON	JavaScript Object Notation
KPI	Key Performance Indicator (if used)
PC	Polyester-Cotton
PK	Primary Key
RTM	Requirements Traceability Matrix
UAT	User Acceptance Testing

1 Introduction

1.1 Background and Study

The textile industry has undergone various changes that can be looked upon in conjunction with the aspects of manufacturing, automation and data management. As Cassels (1959) noted, “technological advances, particularly the use of computers and pre-programmed machines,” have played a transformative role in industrial automation, especially in manufacturing sectors. While modern computers are automated machines have deeply integrated into the fabric of textile industry, there are still areas where textile firms rely on the very rudimentary level methods of storing inventories. A sensible involvement in mathematics and programming can give rise to a higher level of efficiency as it can improve measures to ensure how to cultivate a higher level of accuracy in ways to record the number of inventories and safely keep them in the warehouse.

The history of figurative numbers traces back to the ancient Greeks and it is a branch of Number Theory that provides a brilliant and effective solution towards inventory counting and management issues. The most intriguing aspect of figurative numbers is how Counting inventory, especially at industrial scale involving thousands of units, can be both time-consuming and prone to errors, underscoring the need for a more reliable system. At industrial level, we need to have systems and procedures that are reliable and efficient (Cassels, 1959). Figurative numbers expand numerically into geometric patterns, such as triangles or squares, allowing for structured arrangement of physical objects like cones, which facilitates easier and faster counting (Agarwal, 2021).

Within the setting of a textile industry, it gets really challenging to count the large number of textile cones, especially in situations where factories have large production volumes coupled with daily shift rotations and the need to keep a record of inventory in rooms where temperature also needs to be in a specific range. All the factors indicate a high level of inefficiency arising due to a vacuum of systematic method of counting and recording the inventory in the textile sector (Carević, Ilić, et al., 2020).

Considering the above stated problem, this study aims to integrate figurative numbers with a computer program that will automate the system of counting and will require very few input variables and will quickly give the total number of inventories in a fraction of the second. This can make the inventory counting and management process highly efficient and thereby minimize the chances of errors and redundancy (Iwaniec & Kowalski, 2004).

1.2 Research Gap, Questions and Objectives:

The textile industry has been working on the principles of maximum care because historically speaking then the chances of having incidents are very high. Use of technology, therefore, becomes extremely important and has always been crucial to the growth of industry (Palvia et al., 2015). Dealing with the processes such as counting the inventory is one of such aspects that require extreme caution because of the reasons pertaining to planning and management of the resources. Over the course of history, the use of a mathematical tool such as figurative numbers has never been used in the textile industry (Asadi et al., 2022). It sparks excitement to be able to introduce a novel concept in the realm of industry to solve a decades long problem. Nevertheless, it will require the use of a software utility that could take different variables as input and then give answers in the most efficient way (Domokos, 2018b).

The whole purpose is to bring efficiency and accuracy in the process of counting the inventory as it would take several hours and that too by more than one personnel. Regardless of the amount of time spent and the number of personnel involved in the task, the process is still not free of errors and lack of accuracy. Unfortunately, business entities in the textile industry have been grappling to bring about as much accuracy as possible (Iwaniec & Kowalski, 2004).

If we manually count the textile cones, the process is likely to have errors. The intention is to deeply analyze how the process of manual counting gets affected by human error and what kind of challenges are faced to execute this task. It is the understanding of this process that will make it more practical to look for the solution (Asadi et al., 2022b).

Research Question

How can figurative numbers and a desktop-based application optimize the cone counting and tracking process in textile production, minimizing human error and enhancing operational efficiency?

This research aims to achieve the following objectives

1. Analysis of existing methods
2. Investigation of Figurative methods
3. Create a desktop-based application for the stated purpose
4. Evaluation of the performance

1.2.1 Analysis of existing methods

This research strives to understand the methods used to count and manage inventory in the textile industry with an emphasis on how human errors lead to operational challenges.

1.2.2 Investigation of Figurative methods

Devising a use of figurative numbers in conjunction with cone counting process to come up with a reliable technique that could be error free and time efficient.

1.2.3 Create a desktop-based application for the stated purpose

Creating a desktop-based computer application in line with the figurative numbers so that it could give results instantly just with the input of real time data in textile factories.

1.2.4 Evaluation of the performance

Once the desktop-based application is created, this research will strive to understand the effectiveness in real-world problems to ensure how well the purpose of the research will be served.

1.3 Definition and Limitations

Accurately and efficiently counting thousands of textile cones remains a significant challenge within industrial inventory management. To address this problem, the present study integrates six core concepts: figurative numbers, process optimization, desktop application development, textile industry automation, Lean Six Sigma, and inventory management. Each concept is carefully defined in the context of this research, its relevance is explained, and its specific scope and boundaries are outlined.

Figurative numbers form a special class of numbers in mathematics, known for their unique geometrical properties. Figurative numbers are numerical values that can be visually represented in geometric shapes like triangles or squares, reflecting inherent mathematical relationships (Agarwal, 2021). Such numbers will form a triangle expanding in size or other as soon as we keep adding the numbers (Papalambros, 2015c). This concept is linked to the arrangement of cones in a sequence of such numbers as they form a square or triangle. Therefore, this study aims to create an algorithm that can be used to create an efficient method of placing the inventory in a certain geometrical pattern so that counting the total number of cones will be easily doable and a time saving task. However, the deeper concepts of abstract mathematics will not be touched as the whole purpose is just to take advantage of the basic geometrical property of figurative numbers (Agarwal, 2021). Using technology for this purpose will just require the input of numbers in the length of cones placed in triangular or square form and the length will be taken in terms of the number of cones. Using such a method will give the total number

of cones instantly by running the algorithm. The goal is to build a highly optimized digital tool that prioritizes speed and performance, making it valuable for industrial operations, making it highly attractive to the textile industry.

Process optimization is a crucial concept that needs to be elaborated, and its limits defined in the context of this thesis. Optimization will refer to the systematic improvement in cone counting and tracking processes According to Tall (2009b), optimization focuses on enhancing both accuracy and efficiency while minimizing time spent on repetitive tasks. At this point, it is worth mentioning that this process of optimization has a scope that limits itself to the counting and tracking process and has nothing to do with manufacturing process or quality control outside cone conditioning. However, this highly optimized version of software will provide great value to the business entities in the textile industry.

Desktop application development will be carried out specifically to facilitate the process of counting and tracking inventory. This will be designed in such a way that the workers will be able to continue the process of counting across the working shifts and keep updating the desktop application by inputting the real time data. The most important aspect of any application is its interface, and this is because it acts like the point of contact between the user and the software. Nevertheless, the software has its limitations when it comes to defining its scope. This software does not incorporate predictive AI features but instead focuses solely on cone counting and tracking. It will just focus on the notion of counting and tracking the cones.

The inventory tracking system is centered around the concept of an efficient digital solution designed to speed up cone counting and tracking within the conditioning room. The scope of this system is bound to the counting of cones and has nothing to do with managing other resources such as raw materials and other aspects of warehouse management.

Textile industry automation in this context specifically refers to the semi-automated process of cone counting and tracking, with a focus on the conditioning room process. It clearly claims no reference to the full-scale automation across the production stages and has limitations in terms of helping in cone management to ameliorate and intensify operational efficiency.

Lean Six Sigma in the context of this study refers to a methodology combining Lean principles of waste elimination and Six Sigma's focus on reducing process variation to enhance operational efficiency and quality (Harry, Mann, De Hodgins, Hulbert, & Lacke, 2011). Within this thesis, Lean Six Sigma serves as a guiding framework to minimize human errors and reduce time wastage in the cone counting process through process standardization and automation. The study particularly applies the Poka-Yoke (error-proofing) concept to prevent data entry mistakes and enhance counting accuracy (Shingo, 1986). However, this research does not fully implement the broader Six Sigma framework (such as DMAIC phases or statistical process control) and remains limited to optimizing inventory counting processes without extending overall manufacturing flow or end-to-end lean operations

1.4 Structure of the study

This thesis is structured to systematically present the research conducted on optimizing the cone counting and tracking process in textile production using figurative numbers and a desktop-based application. The subsequent chapters are organized as follows, as illustrated in Figure 1:

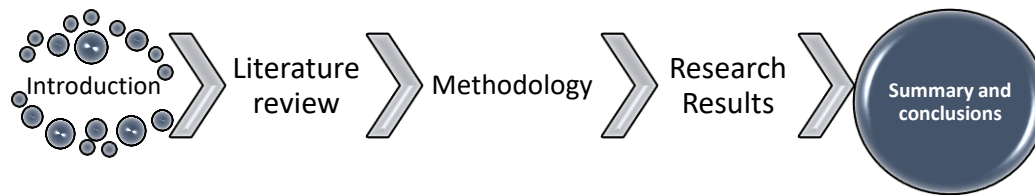


Figure 1. Structure of the Studies.

Chapter 1: Introduction

The background of the study is presented in this chapter, making it possible to start with the research. Problems are outlined, research gaps, and objectives are formulated, the highlighted research questions are also formulated. The scope of the study is explained and why it is important, and an overview is of the cone counting and tracking processes used in textile production.

Chapter 2: Literature Review

The Review of Literature chapter offers an introduction to the existing research work on the study. It looks at past work in the areas of figurative numbers, inventory management, and process optimization. This chapter fills the gap in our existing literature by describing how this research is planned to fill those gaps.

Chapter 3: Methodology

In the methodology chapter, we explain the research approach and the steps I took to perform the study. It describes the design and development life cycle of the desktop application and methods of acquisition data and evaluation of the system's behavior. In addition, it discusses how the research was carried out and analyzed.

Chapter 4: Results

The results from the study are presented in this chapter. The discussion includes quantitative results from the implementation of the desktop-based application i.e., improvement in accuracy and efficiency and qualitative feedback from the users. The performance of the new system is also compared to traditional manual methods.

Chapter 5: Conclusion and Future Work

This final chapter summarizes the core findings of the study and highlights its contributions to the domain of inventory optimization in textile manufacturing. The research prioritizes practical application and offers actionable recommendations for how textile factories can integrate the cone counting application into daily operations. Finally, the chapter outlines future research directions, such as enhancing system features and broadening its applicability to other inventory types beyond cones.

2 Literature Review

The textile industry offers a wide variety of products, which results in a complex supply chain. This complexity highlights the need for advanced and efficient methods to manage inventory and keep track of stock effectively. Textile industry holds a paramount significance in the global manufacturing industry, but it faces persistent challenges caused by human errors made with regards to the management of the inventory, particularly when it comes to counting the cones (Chopra & Meindl, 2015). Fortunately, phenomena such as mathematical modelling, especially the one pertaining to figurative numbers, have turned out to be very useful for various industries in a variety of ways (Cassels, 1959; Iwaniec & Kowalski, 2004). Triangular numbers, a subset of figurative numbers, represent values that can be arranged in a triangle where each row contains one more item than the previous (Agarwal, 2021). The application of figurative numbers in industrial inventory systems remains largely unexplored in the arena of inventory management, especially in the textile industry. Therefore, the literature review is an attempt to shed some light on the synthesis of the theoretical foundation of the triangular numbers, how well they can be related to the organization of inventory and dig deeper into the notion of applying them into the textile industry. Moreover, it analyses the role of process optimization, digital inventory management, and desktop-based applications in maximizing operational efficiency in the textile industry (Asadi et al., 2022b).

2.1 Current State of Inventory Management in Yarn Manufacturing Industry

Inventory digitization in the yarn manufacturing sector has traditionally relied on established industrial engineering tools such as Just-in-Time (JIT), RFID systems, and, more recently, image processing. These methods aim to reduce holding costs (JIT), improve traceability (RFID), and automate quality checks (image processing) (Ghelichi & Abdelgawad, 2014). However, these solutions often face limitations in high-volume, low-

margin environments typical of textile production, RFID systems are costly and susceptible to environmental interference, while JIT frameworks struggle with unpredictability in yarn demand and supply variability.

While these tools focus on real-time tracking and lean inventory, figurative numbers provide a fundamentally different approach rooted in mathematical modelling. Unlike RFID or barcode systems that require hardware infrastructure, figurative numbers use spatial patterns (e.g., triangular numbers) to model physical inventory arrangements, allowing for quick, low-cost, and error-resistant counting through deterministic formulas (Agarwal, 2021). This makes them particularly valuable in small to mid-sized facilities where digitization budgets are limited.

By combining principles from number theory and industrial systems analytics, the use of figurative numbers represents an interdisciplinary innovation that complements traditional inventory technologies. Their integration into desktop-based applications enhances accuracy and process visibility without the overhead of more complex systems, filling a key gap identified in operations research for accessible yet efficient inventory solutions in the textile industry.

2.2 Figurative Numbers

When physical objects are arranged according to sequences formed by figurative numbers, they exhibit geometric properties that are useful for modeling arrangements such as triangles and squares (Agarwal, 2021). These numbers are also called polygonal numbers, and they can be arranged to form shapes of geometrical figures such as triangle, square or pentagon (Domokos, 2018b). In the field of mathematics, figurative numbers have been studied extensively to understand the various properties (Carević et al., 2020c). Figurative numbers such as triangular numbers or square numbers are the ones that provide a systematic approach to counting and arrangement. Focusing again on triangular numbers, then the objects if arranged in triangular number sequence then

every successive row has a greater number of items than the preceding one. This structure allows for efficient computation using closed-form expressions, making triangular patterns ideal for fast inventory estimates (Carević et al., 2020c).

Talking about it in the computational contexts, figurative numbers have been used in the Pascal's Triangle (Carević et al., 2020c). This highlights their potential use in computational purposes. Tall (2009b) demonstrated the use of functions that can be used to generate sequences associated with the various geometrical figures, hinting their applicability in modelling the physical arrangement of objects in three dimensions. It is this idea that will be investigated to understand how it can be used in the textile industry.

Tall (2009b) proposed that the geometrical properties of the figurative numbers provide an opportunity to come up with a spatial arrangement of the objects such that it will be conveniently possible to put them in a predictable pattern. For instance, if the cones in the textile factories are placed in a triangular or square pattern, this would allow a rapid counting using math formula that can be associated with the triangular or square number sequences (Agarwal, 2021). Nevertheless, this aspect of figurative numbers has been unexplored, and this review will take a step ahead to find how well this concept can be exploited to reap benefits in the textile sector.

2.3 Inventory Management Challenges in the Textile Industry

Textile industry has a diverse set of activities going on in the and this is owing to the fact they have a high production volume which requires an enormous supply of raw material that can be as many as in millions (Chopra & Meindl, 2015). Efficient inventory counting, organization, and management are central to the operations of the textile industry, but this is a task that often falls prey to human errors and mismanagement. Strangely enough, the world has become technologically advanced and modern in its truest sense, but in the textile industry, they still rely on the manual counting of the cones. As these cones are incredibly huge in number, therefore the staff members make several mistakes

in manual counting of the inventory that negatively affects the production planning and resources allocation. These inaccuracies bring about a lot of inefficiencies which then translate into huge financial losses over a period. It is crucial to streamline this whole process of inventory management through using some computer-based technology (Palvia et al., 2015).

The situation needs to be viewed in conjunction with the environmental factors that are in play. Textile industries have factories working under a strict environment whereby they can have a certain temperature and humidity level and because of the high temperature and humidity level, manual counting becomes even more daunting task which is certainly more prone to errors. Considering the facts stated above, the inventory management practices seem to be outdated and appear as a hurdle to the operational efficiency, and this could be sorted by creating an automated process rooted in a mixture of mathematics and technology (Asadi et al., 2022b).

2.4 Process Optimization and Automation

Optimization of processes in the textile sector may involve maximizing accuracy, the speed at which the processes occur and minimizing the wastages resources. However, there are ways such as mathematical modelling combined with computational tools that can push down human intervention to a considerable extent and as a result improve efficiency and reduce financial losses (Iwaniec & Kowalski, 2004). While it is undeniable that various stages of manufacturing in the textile industry have been automated already, inventory management has still lagged and still awaits the involvement of technology and advancement.

Already existing concepts such as design science stress the development of artefacts such as software utilities with an application into practical problems (Papalambros, 2015c). It is therefore the aim of this paper to come up with a desktop-based solution that would be guided by the principles of figurative numbers for inventory counting.

Computer scientists and mathematicians have unanimously agreed on the undisputable part analytic number theory in optimizing computational processes, hinting the concepts of mathematics such as figurative numbers can be used in a variety of ways (Cassels, 1959; Iwaniec & Kowalski, 2004). Pertinently relating to the topic of the study, the figurative numbers can be used to create an algorithm. An algorithm that can be used to calculate the number of cones in manufacturing units just by inputting the number of cones in the first row of the cones arranged in a triangular arrangement. This will instantly give the total number of cones, significantly reducing the total number of cones. This will also reduce the probability of making errors, leading to inaccuracies and thereby financial losses (Carević et al., 2020c).

Other industries such as retail and logistics have also used technologies ranging from RFID and barcode scanning that have helped a lot in inventory tracking and management (Chopra & Meindl, 2015). This has hugely reduced the financial losses arising due to reasons related to human errors. It is however unfortunate that this technology cannot be used in the textile industry because each cone will need to have an individual identifier and in the warehouse of a textile industry, these are stored in bulk, thus the idea might not be practically feasible. As a foregone conclusion, there must be an alternative method that could be used to overcome this limitation and within the scope of this study a desktop-based utility grounded into a mathematical solution has been identified as an alternative method of resolving this issue of inventory management.

Personnel working at the manufacturing units are skilled at specific tasks performed within their field. As a result, it is hard to expect them to be technologically literate to be able to conveniently work their way through complex software programs. There must be a direct and easy way for the workers to be able to count the number of cones accurately and quickly. It is for this reason the desktop-based utility must be sufficiently easy to use and quick to operate. Nonetheless, there is a gap between the studies which have integrated mathematical optimization to intensify automation in the textile

industry. The purpose of this study is to explore the ways to explore the concept of figurative numbers so that they can devise a desktop-based application to speed up the process of cone calculation at the same time to ensure there are no errors that can turn out to be huge financial losses in the long-term (Palvia et al., 2015). In the existing sphere of academia, there has not been a case whereby figurative numbers were used to automate the process of inventory calculation process in the textile industry.

2.5 Desktop-Based Applications for Inventory Management

To ensure that desktop-based applications for inventory management are not only mathematically sound but also practically usable, it is essential to bridge mathematical modelling with system design and human-computer interaction (HCI). The integration of figurative numbers into inventory counting is not only a mathematical innovation but also a design challenge that must accommodate user behavior and task environment. HCI literature (Norman, 2013) emphasizes usability, error prevention, and user feedback, all of which were incorporated into the application through Poka-Yoke principles and iterative design improvements. Additionally, the socio-technical systems theory (Trist & Bamforth, 1951) highlights the interdependence of social and technical subsystems, justifying the need for simple, context-sensitive tools like desktop-based applications for non-technical workers in textile factories. This theoretical grounding links mathematical modelling with interface design, reinforcing the interdisciplinary approach of the research.

There is more than one benefit of using a desktop-based application and these can be deemed in terms of automating the inventory management process as well as real time data processing that can then be linked with already existing databases. Appositely in the textile industry, desktop-based application can also easily incorporate the factors associated with the large inventory volumes and shift rotations. These can be done by instant calculations and tracking of the inventory. The process will certainly reduce the

errors made in the manual calculation of the cone counting process (Papalambros, 2015c).

Currently, there are desktop-based solutions used in the textile industry that focus mainly on the aspect of supply chain ranging from tracking the raw materials and finished goods. It is the point where the need to have an automated system in place where the cone counting process can be done instantly in a manner that is free of any possible errors. Developing such a system offers operational advantages for both management and factory workers by enabling faster, error-free execution of repetitive tasks (Palvia et al., 2015). Surprisingly enough, there does not exist any notion of such an automated utility in the current literature.

Anyhow, the development of desktop-based application requires considering certain factors such as compatibility with the database system because this is a big challenge in the textile industry has, they make use of a diverse range of software and the introduction of a new desktop-based application that needs to be in place must seamlessly integrate with the already existing software. However, the proposed software solution here will be aiming to address the problem of integration with the pre-existing software in the textile industry (Palvia et al., 2015).

2.6 Research Gaps

Generally figurative numbers are famous in the field of mathematics, and they have been thoroughly researched, and various aspects have been researched and explored (Agarwal, 2021; Domokos, 2018b). Nevertheless, their application in the optimization of computational activity with regards to the counting of cones in the textile industry has not been researched and it is nearly non-existent in the current literature. The fact that figurative numbers offer a remarkable solution to the geometrical arrangement of the objects, yet no studies have been conducted to exploit the properties of these numbers to the advantage of humans. Additionally, the textile industry has heavy dependence on

manual processes thus creating an unavoidable possibility of leading to the errors made by people working there. On top of that, there is a clear absence of a tailored solution to address the problem of the cone counting process in the quickest and most efficient way possible.

This literature review highlights the possible use of figurative numbers, optimization of inventory management processes and developing a desktop-based application that will be based in the figurative numbers (Carević et al., 2020c; Papalambros, 2015c). If on one hand, the figurative numbers can be easily used to create systematic counting processes, on the other hand a desktop-based application can be used to reduce errors drastically and the process will become more efficient. The absence of integration between these domain sheds light on the research gap. By creating a desktop-based application that draws on the use of geometrical properties of figurative numbers, this literature reviews a user-friendly solution that will take leap forward into academic research and industrial practice as well.

3 Design and Development of the Application

The DSR framework, as applied in this research, is illustrated as a flowchart in Figure 3.4, outlining the iterative stages from problem identification to evaluation. Providing a structure for problem identification, solution development, and evaluation. The DSR approach has generally been used for development and evaluation of solutions to solve the real-world problems. The focus of this research is to develop a system which is composed of figurative numbers integrated with desktop applications to streamline the process of cone counting in the yarn manufacturing industry. Different steps of the design science research approach in figure 2 are described in the following sections.

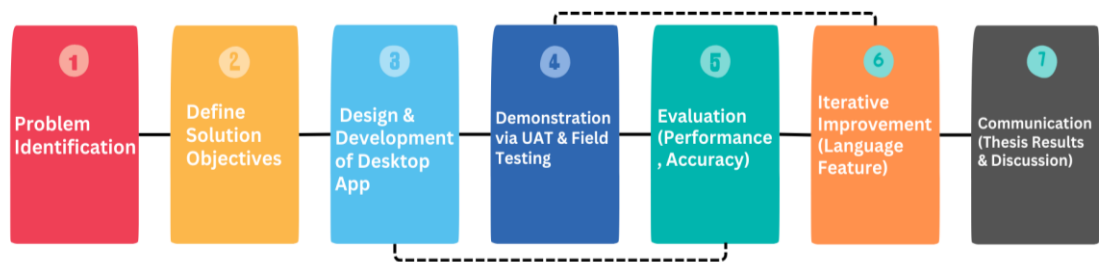


Figure 2. Design Science Approach.

The diagram illustrates how users interact with the desktop interface built using Tkinter. Input values are processed by the figurative number algorithm, and outputs are stored locally using JSON and Excel files. Supporting libraries like Matplotlib and Winsound enhance interactivity and visualization.

3.1 Identification and Motivation

In the yarn spinning sector of the textile industry, maintaining the humidity of yarn is very crucial for the quality of the product. As shown in Figure 2, the cones are stacked in

a symmetrical layout in the humidity room, which poses challenges in manual counting due to their volume and arrangement. As the cotton passes through various machines during processing, it undergoes a significant reduction in moisture content. For this purpose, specific conditioning rooms have been designed where cones are placed to retain the humidity. However, many challenges have been faced during this process.



Figure 3. Cone Stacks in the Humidity Room of the Case Company.

Manual counting errors: Manual counting during high production periods often leads to unreliable inventory records, misused resources, and challenges in accurately evaluating output efficiency (Chopra & Meindl, 2015). Such errors cause contradictions in the inventory records, misallocation of resources, and difficulties in tracking production efficiency.

Inefficient Data Recording and Entry: In the current workflow, workers initially log data by hand, which is later transcribed into the system—introducing delays and a higher probability of human error during data entry, a known bottleneck in similar production environments (Hevner et al., 2004).

The motivation for this research arises from the need to address inefficient processes, aiming to enhance cone counting system and simplify data collection and management. A desktop application will be developed to automate counting and data collection processes.

The proposed solution involves the following key components:

- Desktop Application Design and Development (with Mathematical Algorithm Development)
- Evaluation of the Desktop Application

In the following section we will describe the design and development process of the desktop application.

3.2 Design and Specification of Desktop application

In this section we will discuss the development of the desktop application which we are developing for the case company. This includes the phases of requirements gathering, mathematical modeling, database architecture, and the creation of an Entity-Relationship Diagram (ERD). The aim of this study is to develop a system which automates the process of cone counting and integrates the real-time data which helps to monitor the progress of the workflow.

3.2.1 Requirements Collection and Definition

The design of the desktop application was initiated after a thorough collection of requirements from the case company. As described by Hevner et al. (2004), the application follows a Design Science Research approach emphasizing iterative problem-solving and continuous refinement. In addition, to prevent human error, Poka-Yoke methods from Lean Six Sigma are applied, such as restricting invalid input values, a

principle advanced by Shingo (1986). For instance, the application restricts stack height inputs to odd numbers only prompting a warning if invalid input is detected. Common user interface safeguards—such as dropdown menus and validation rules help minimize user input mistakes. This aligns with HCI best practices for error prevention (Shneiderman & Plaisant, 2005).

Below is a table that outlines the key requirements gathered from the company case:

Table 1. List of requirements for the Cone Counting Desktop application.

Requirement ID	Description
REQ1	Automate the counting of textile cones to reduce manual errors and improve counting accuracy.
REQ2	Providing tangible reports for the managers to share with stakeholders as per the requirements.
REQ3	Keep a track for individual workers activities for auditing and ensuring accountability.
REQ4	Develop a user-friendly dashboard to provide decision-makers with real-time analytics and insights into production metrics, facilitating informed decisions.

The operational staff together with decision-makers at the case company identified an efficient automated system as their essential requirement. The vital requirements established a base for designing the desktop application before its execution.

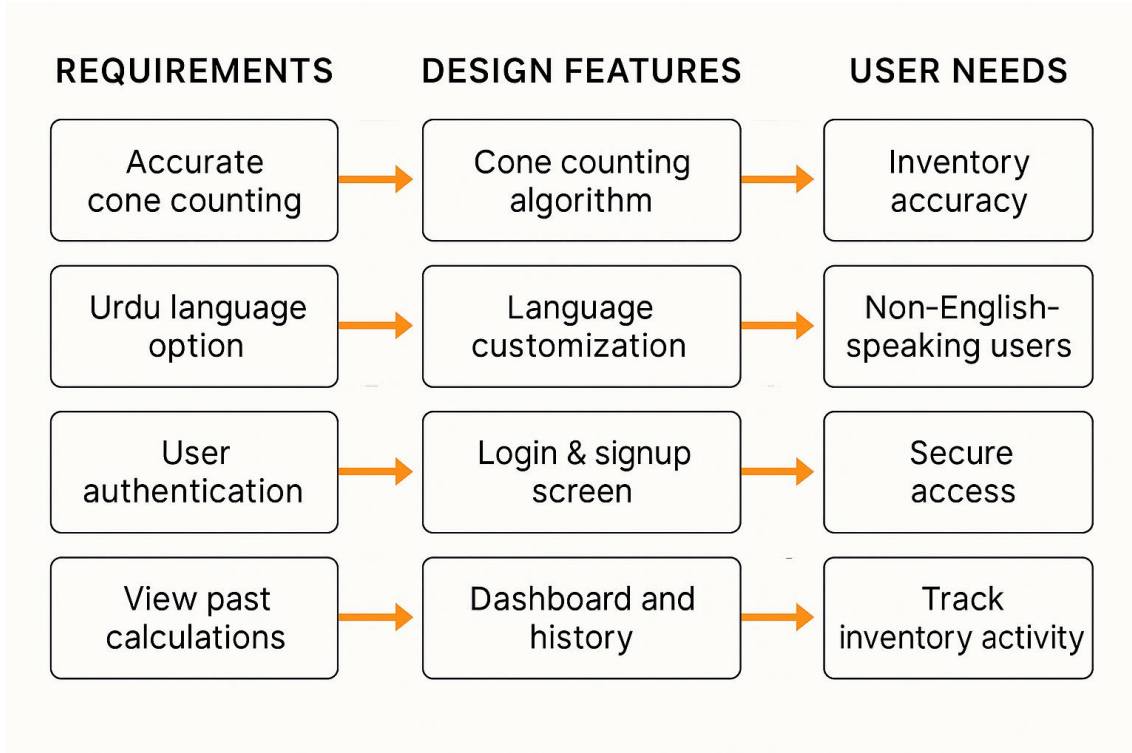


Figure 4. Visual Requirements Traceability Map.

Figure 4 illustrates how each requirement informed a specific design feature, which in turn addressed key user needs. The flow ensures that system design remained tightly aligned with both stakeholder goals and user expectations.

3.2.2 Mathematical modelling

In this section, we aim to determine the total number of points in a cone stack characterized by a height α , where the number of points in each layer follows a specific quadratic pattern. We proceed systematically, observing the stack's structure, defining its properties, and deriving a general formula, followed by a justification for restricting α to odd integers and a concrete example.

Observing the Stack's Structure

Consider a stack composed of α layers, where α is a positive integer representing the height. We index the layers from $i = 1$ at the top to $i = \alpha$ at the bottom. The stack structure, illustrated in Figure 3, shows a quadratic pattern with symmetry around a

central layer, justifying the requirement of an odd height for accurate modelling. As we move upward from this center, the number of points decreases, and as we move downward, it increases, suggesting a pattern that can be modeled mathematically.

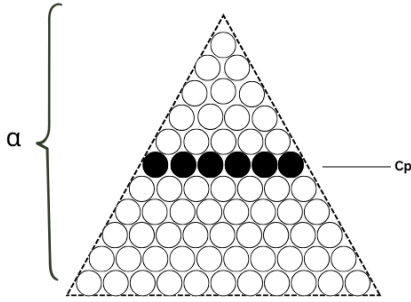


Figure 5. Symmetrical cone stacking pattern demonstrating layer-wise quadratic structure.

To ensure this symmetry, we restrict α to the set of odd positive integers, defined as:

$$\alpha \in A_{odd} = \{2\kappa + 1 \mid \kappa \in \mathbb{N}_0\} \quad (1)$$

Where $\mathbb{N}_0 = \{0, 1, 2, 3, \dots\}$ denotes the non-negative integers. For $\alpha = 2\kappa + 1$, the central layer's index, denoted C_p is:

$$C_p = \frac{\alpha + 1}{2} = \frac{(2\kappa + 1) + 1}{2} = \kappa + 1 \quad (2)$$

Since κ is a non-negative integer, C_p is a positive integer, confirming the existence of a unique central layer when α is odd.

Modeling the Number of Points per Layer

Let η_i represent the number of points in the i -th layer. We propose that η_i follows a quadratic function centered at C_p , reflecting the observed symmetry:

$$\eta_i = c \cdot d + (i - C_p)^2 \quad (3)$$

Here, c and d are positive integers corresponding to the width and length of the central layer, respectively, such that $c \cdot d$ the base number of points at $i = C_p$. The term $(i - C_p)^2$ introduces a quadratic increase in points as the layer index deviates from the center, ensuring that layers equidistant from C_p (example, $i = C_p - m$ and $i = C_p + m$) have identical point counts:

$$n_{c_p-m} = c \cdot d + (C_p - m - C_p)^2 = c \cdot d + m^2 \quad (4)$$

$$n_{c_p+m} = c \cdot d + (C_p + m - C_p)^2 = c \cdot d + m^2 \quad (5)$$

This symmetry is a key feature of our model.

Step 3: Computing the Total Number of Points

The total number of points in the stack, $T(\alpha, c, d)$, is the sum of η_i over all layers:

$$T(\alpha, c, d) = \sum_{i=1}^{\alpha} \eta_i = \sum_{i=1}^{\alpha} c \cdot d + (i - C_p)^2 \quad (6)$$

This sum can be separated into two components:

$$T(\alpha, c, d) = \sum_{i=1}^{\alpha} c \cdot d + \sum_{i=1}^{\alpha} (i - C_p)^2 = c \cdot d \cdot \alpha + \delta(\alpha) \quad (7)$$

Where $\delta(\alpha) = \sum_{i=1}^{\alpha} (i - C_p)^2$ is the sum of squared deviations from the central layer.

To evaluate $\delta(\alpha)$ we reindex the sum using $j = (i - C_p)$. For $\alpha = 2k + 1$, i ranges from $2k + 1$, and j ranges from $1 - (k+1) = -k$ to $2k + 1 - (k + 1) = k$. Thus:

$$\delta(\alpha) = \sum_{j=-k}^k j^2 \quad (8)$$

Since the square function is even, we can exploit symmetry:

$$\delta(\alpha) = \sum_{j=-k}^{-1} j^2 + \sum_{j=1}^k j^2 = 2 \sum_{j=1}^k j^2 \quad (9)$$

We now apply Gauss's summation (Apostol, 1998) formula for the sum of squares:

$$\sum_{j=1}^k j^2 = \frac{k(k+1)(2k+1)}{6} \quad (10)$$

Thus:

$$\delta(\alpha) = 2 \cdot \frac{k(k+1)(2k+1)}{6} = \frac{k(k+1)(2k+1)}{3} \quad (11)$$

Express k in terms of α since $\alpha = 2k + 1$, we have $k = \frac{\alpha-1}{2}$ Substitute:

$$\delta(\alpha) = \frac{\left(\frac{\alpha-1}{2}\right)\left(\frac{\alpha-1}{2}+1\right)\left(2 \times \frac{\alpha-1}{2}+1\right)}{3} = \frac{\left(\frac{\alpha-1}{2}\right)\left(\frac{\alpha+1}{2}\right)\alpha}{3} \quad (12)$$

Simplify:

$$\delta(\alpha) = \frac{(\alpha-1)(\alpha+1)\alpha}{12} = \frac{\alpha(\alpha^2-1)}{12} \quad (13)$$

Therefore, the total number of points is:

$$\mathbf{T}(\alpha, \mathbf{c}, \mathbf{d}) = \mathbf{c} \cdot \mathbf{d} \cdot \mathbf{a} + \frac{\alpha(\alpha^2-1)}{12} \quad (14)$$

Justification for Odd α :

We now address why α must be odd. If α is even, say $\alpha = 2k$, the central pivot becomes:

$$C_p = \frac{\alpha+1}{2} = \frac{2k+1}{2} = k + 0.5 \quad (15)$$

This is not an integer, indicating that no single layer serves as the center. Instead, the stack has two middle layers (at indices k and $k+1$), breaking the symmetry required for

our quadratic model. The absence of a unique c_p prevents the consistent pairing of layers, complicating the summation and rendering the formula inapplicable in its current form.

Example Verification

To illustrate, consider a stack with $\alpha = 11$ and $c_p = 6$ width $c = 78$ and length $d = 88$. The number of points per layer is calculated using equation (3):

$$n_i = 78 \times 88 + (i - 6)^2$$

Compute the total using equation (14):

$$T(11,78,88) = 78 \times 88 \times 11 + \frac{11(11^2 - 1)}{12}$$

First,

$$78 \times 88 = 6,864, \text{ then } 6,864 \times 11 = 75,504. \text{ Next, } 11^2 = 121, \text{ } 121 - 1 = 120 \text{ and } \frac{11 \times 120}{12} = 110.$$

Thus,

$$T = 75,504 + 110 = 75,614$$

Verify by direct summation:

$$\delta(11) = \sum_{i=1}^{11} (i - 6)^2 = 0^2 + 1^2 + 2^2 + 3^2 + 4^2 + 5^2 + 5^2 + 4^2 + 3^2 + 2^2 + 1^2 = 0 + 1 + 4 + 9 + 16 + 25 + 25 + 16 + 9 + 4 + 1 = 110 \text{ matching our results.}$$

For a stack of odd height α , the total number of points is calculated using equation (14):

$$T(\alpha, c, d) = c \cdot d \cdot \alpha + \frac{\alpha(\alpha^2 - 1)}{12}$$

This formula, derived from using a quadratic model and Gauss's summation, is valid only for odd α due to the necessity of a unique central layer, as demonstrated. The example confirms its accuracy, solidifying our approach.

3.2.3 Desktop App Design

The Cone Calculator application is a desktop-based solution that streamlines production monitoring through real-time calculations, data logging, and visualization. The system uses Python's powerful standard library along with several third-party packages to provide smooth user experience. This section outlines the overall architecture, key modules, and integration of various technologies.

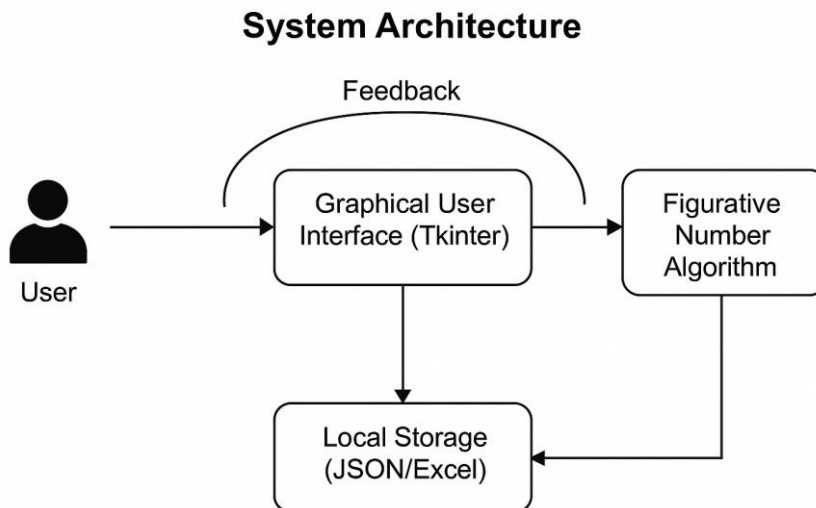


Figure 6. System Architecture of the Cone Counting Application.

Figure 5 illustrates how users interact with the desktop interface built using Tkinter. Input values are processed by the figurative number algorithm, and outputs are stored locally using JSON and Excel files. Supporting libraries like Matplotlib and Winsound enhance interactivity and visualization.

Technologies Used

The application leverages the following Python libraries, each selected for its specific role in supporting the design:

- **Tkinter:** Used to create the graphical user interface (GUI), providing widgets and layout tools to build an intuitive and interactive desktop experience. Tkinter was selected over other frameworks such as PyQt or Kivy because of its lightweight nature, built-in availability in Python, and ease of deployment in resource constrained environments. Since the application is designed for use in a textile factory setting often involving non-technical users and limited hardware capabilities. Tkinter offers a low-overhead solution that supports basic interface needs without requiring additional installations or complex dependencies. Its simplicity makes it ideal for developing reliable, easily maintainable applications suited for quick adoption by factory staff.
- **JSON:** Employed for lightweight, persistent storage of user credentials, application settings, and preferences, ensuring easy data access and management.
- **Openpyxl:** Facilitates interaction with Excel files to store calculation records in a structured format, enabling organized data logging and retrieval. The decision to use local Excel-based storage instead of a centralized database (such as MySQL or PostgreSQL) was based on the operational context of the target environment. Many small- to mid-sized textile factories operate with limited IT infrastructure and lack constant internet connectivity or dedicated database servers. Local Excel files allow for offline functionality, quick setup without additional backend systems, and easy access for users and supervisors who are already familiar with spreadsheet formats. This ensures seamless data handling without increasing system complexity.

- **Matplotlib:** Generates graphical visualizations, such as bar and line graphs, to display production trends and usage statistics.
- **OS:** Manages file system operations, ensuring required files are present and properly handled during application execution.
- **Datetime:** Provides time-to-grammatic capabilities to organize and track calculation records over time.
- **Tkinter.messagebox:** Displays dialog boxes for user feedback, including error messages and success notifications, to enhance user interaction.
- **Winsound:** Plays sound alerts for key events, such as calculation completion, to improve user engagement.
- **Collections. Counter:** Counts occurrences in data, such as yarn types, to support the generation of usage summaries and statistics.

Entity Relationship Diagram: The entity relationship diagram is used to understand the structure and interrelation of key data components. The diagram shows us the visualization of the attributes and their characteristics involved in the cone counting application. This explanation clarifies how data is entered into a system, processed, and how the resulting output interacts within the system. As shown in Figure 4, the Entity-Relationship Diagram outlines the relationships between core entities such as Workers, Input, and Output within the database.

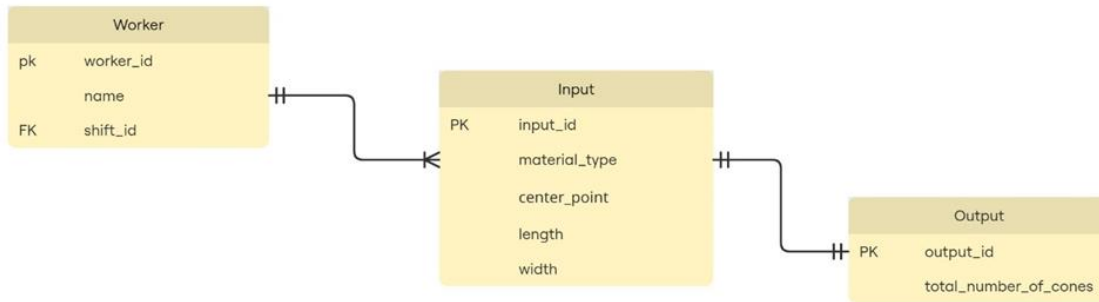


Figure 7. Entity-Relationship Diagram (ERD) showing system components and relationships.

Entities and Attributes

The ERD consists of three core entities:

- **Worker**
Attributes: worker_id (PK), name, shift_id (FK)
- **Input**
Attributes: input_id (PK), material_type, center_point, length, width
- **Output**
Attributes: output_id (PK), total_number_of_cones

Relationships Between Entities

- **Worker to Input:** One-to-many (A worker can record multiple input datasets during a shift, linking manual observations or material records with the system).
- **Input to Output:** One-to-one (Each input entry corresponds to a single computed output, representing the total number of cones derived from the geometric model).

Pseudocode for Core Calculation

The following high-level pseudocode outlines the design of the core cone counting calculation, based on a quadratic model for stacks with odd heights:

```

START
DECLARE integer variables: height, center_cones, other_cones, center_point, sum_above,
sum_below, total_cones
INPUT height
IF height is odd THEN
    SET center_point = (height + 1) / 2
ELSE
    DISPLAY "Height must be odd"
    TERMINATE
END IF
INPUT center_cones
INPUT other_cones
SET sum_below = 0
SET sum_above = 0
FOR i FROM 1 TO height DO
    IF i < center_point THEN
        ADD absolute ((i * i) - (center_point * center_point)) TO sum_below
    ELSE IF i > center_point THEN
        ADD absolute (i * i) - (center_point * center_point) TO sum_above
    END IF
END FOR
SET total_cones = (center_cones * other_cones * height) + (sum_above - sum_below)
DISPLAY total_cones
END

```

Interactions and Data Flow

1. **User Interaction:** Workers interact with the application through a desktop based graphical interface. They input data related to cone dimensions and trigger calculations.
2. **Data Validation and Logic Flow:** The backend checks the validity of the input values, especially ensuring that the height is an odd number to align with the logic of the figurative number algorithm.
3. **Algorithm Execution:** Upon valid input, the figurative number algorithm calculates the total number of cones based on the provided parameters. This is a key computational step.
4. **Data Storage:** Instead of using an online database, the system stores both input and output data locally in Excel sheets. These sheets are structured and labeled for each shift and can be accessed by managers for performance tracking.
5. **Dashboard Interaction:** The frontend displays real-time feedback from the algorithm, including production counts and shift metrics. This gives workers instant visibility into their productivity.
6. **Managerial Insight Generation:** At any point, managers can open the saved Excel sheets to monitor:
 - Shift-wise output
 - Worker performance
 - Input trends (e.g., most common dimensions) This local data storage supports decision-making and process optimization.

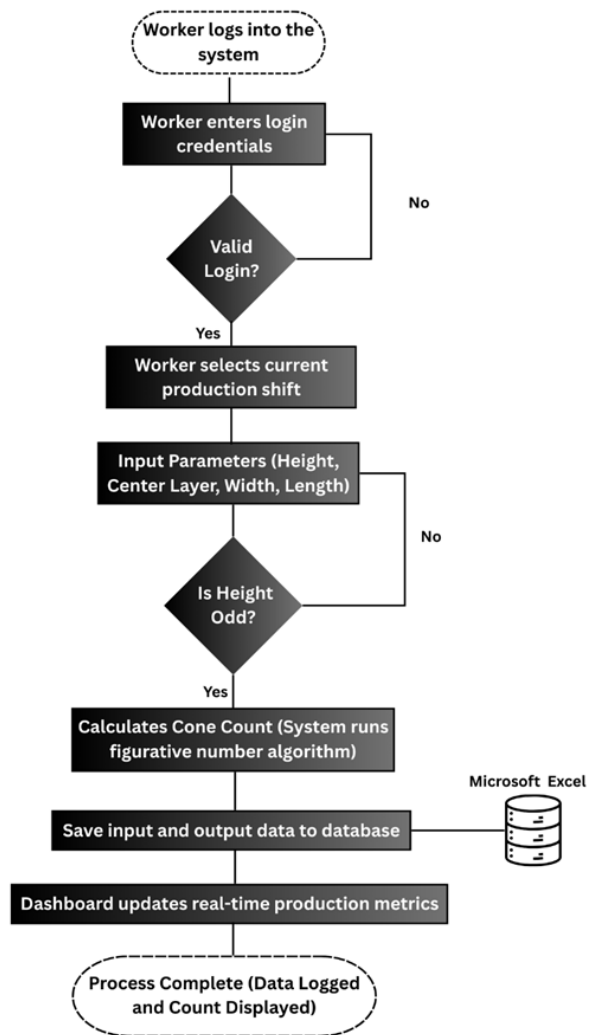


Figure 8. Flowchart representing the Design Science Research (DSR) framework used for application development.

This system makes the whole process smooth and simple, which helps track the production flow. With simple data entry and automatic calculations, it helps managers with useful insights to improve efficiency and decision-making.

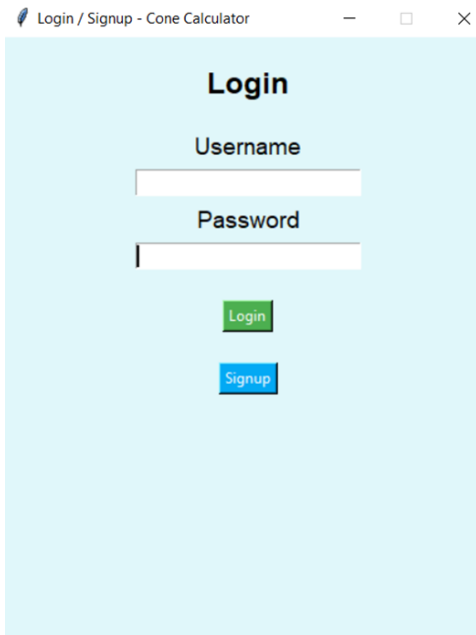
3.3 Development of the Desktop App

3.3.1 User Authentication Interface

The initial page of the desktop application serves as the user authentication interface. It includes the following elements:

- **Username Input Field:** Allows users to enter their unique username or email associated with their account.
- **Password Input Field:** Secures user access by requiring the corresponding password.
- **Login Button:** Authenticates existing users and redirects them to the main functionality of the application upon successful login.
- **Signup Option:** Provides new users with the ability to create an account, ensuring personalized access and secure data handling.

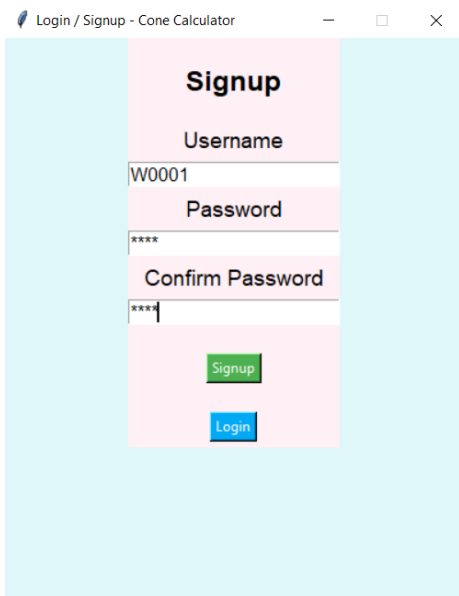
This login system makes sure that only registered users can access the app's features, which helps keep the data safe and organized. The login screen, including username and password fields, is shown in Figure 6.



The screenshot shows a web browser window titled "Login / Signup - Cone Calculator". The page has a light blue background and a central white form area. At the top of the form, the word "Login" is displayed in bold black text. Below it, there are two input fields: "Username" and "Password". Underneath the "Password" field, there are two buttons: a green "Login" button and a blue "Signup" button.

Figure 9. User login and authentication interface of the Cone Counting Application.

Upon successful login or signup, users are directed to the second page, which is equipped with a top menu bar containing four key tabs: Home, Dashboard, History, and Settings. And if the user is Logging in for the first time, they can go to the sign-up option shown in Figure 8, where they can put their username and password, and their user id will be stored in the desktop database for the future authentication.



The screenshot shows a web browser window titled "Login / Signup - Cone Calculator". The page has a light blue background and a central white form area. At the top of the form, the word "Signup" is displayed in bold black text. Below it, there are three input fields: "Username" (containing the text "W0001"), "Password" (containing four asterisks "****"), and "Confirm Password" (containing four asterisks "****"). Underneath the "Confirm Password" field, there are two buttons: a green "Signup" button and a blue "Login" button.

Figure 10. User Signup interface of the Cone Counting Application.

3.3.2 Cone Calculation Interface

In the Home tab, users are prompted to input key information regarding yarn type, stack height, and cone placement. Upon successful login or signup, users are directed to the second page, which is equipped with a top menu bar containing four key tabs: Home, Dashboard, History, and Settings.

The screenshot displays the 'Cone Calculator - Mohsin' application window. The interface is divided into two main sections: 'Calculate' and 'Quick Stats'.

Calculate Section:

- Yarn Type:** Polyester: Cotton (52:48)
- Stack Height:** 9
- Center Cones:** 200
- Other Cones:** 110
- Shift:**
 - Morning
 - Evening
 - Night
- Notes (optional):** (Empty text field)

Below the input fields are four buttons: 'Calculate' (green), 'Save Favorite' (orange), 'Load Favorite' (green), and 'Reset Form' (grey). At the bottom of this section, the result is displayed: **Total Cones: 198060**.

Quick Stats Section:

- Recent Calc: None
- Today's Cones: 519704
- Favorite Yarn: Polyester: Cotton (52:48)
- Last Weight: 0g

Figure 11. Main interface of the application for cone calculation with input fields and statistics.

As seen in Figure 7, the main interface allows users to input cone data, select yarn type and shift, and perform automated calculations. After successfully logging in, users are directed to the main calculation page of the application. This interface allows users to calculate the total number of yarn cones based on specific input parameters. Here's how it works:

- **Yarn Type:** Users begin by selecting the type of yarn from a dropdown menu (e.g., Polyester: Cotton 52:48).

- **Stack Height:** The height of the yarn cone stack must be entered. This value must be an **odd number**; otherwise, the system will display an error, as the calculation is based on a central cone reference.
- **Center Cones & Other Cones:** Users count the number of cones in the central row and add the number of cones in the rows in front and behind the center row. For example, if the stack height is 7, the center point is row 4. Users should count cones in row 4 (center cones) and rows 1–3 and 5–7 (other cones).
- **Shift Selection:** Users must specify the work shift (Morning, Evening, or Night) during which the cones were processed.
- **Optional Notes:** A text box is available for entering any relevant notes.

Once the necessary data is filled in, users click the "Calculate" button to get the total number of cones. The result is displayed at the bottom in green.

Additional features include:

- **Save Favorite:** Saves frequently used yarn types for quick access.
- **Load Favorite:** Loads previously saved favorites.
- **Reset Form:** Clears all input fields for a fresh calculation.

On the right side, the **Quick Stats** panel shows information such as:

- The total number of cones calculated for the current day.
- The user's favorite yarn type.
- The most recent calculation data.

3.3.3 Dashboard and History

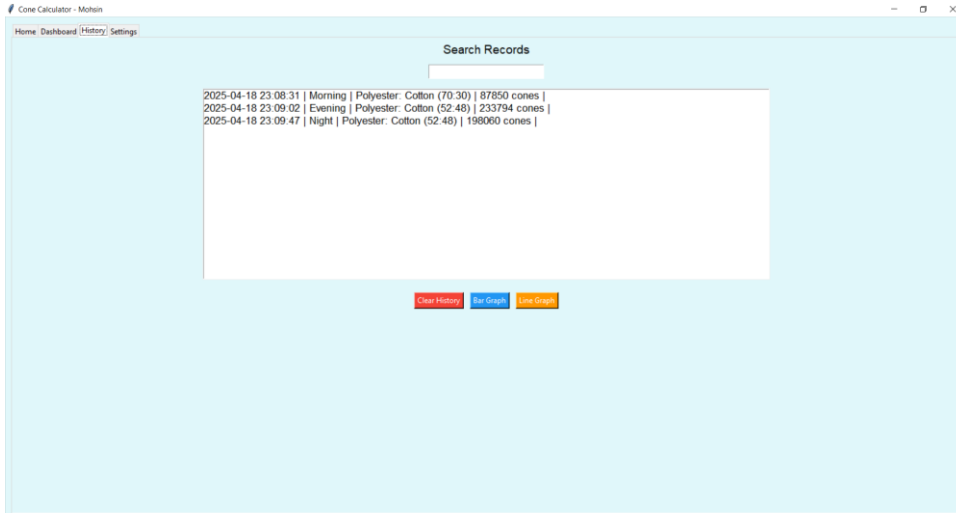


Figure 12. Dashboard and history tab displaying past calculations and user summaries.

Figure 8 displays the Dashboard and History tab, providing users with access to their past entries and calculation summaries. Besides the main calculation page, the app also has a Dashboard and a History section that help users keep track of their work.

Dashboard

The dashboard gives you a quick overview of your activity. It shows:

- The total number of entries you've made.
- A summary of how many cones were calculated today.

It's a handy way to stay updated on your daily progress without digging through all the details.

History

The history section stores all your past calculations. It shows:

- What yarn type you used
- Stack height and cone details
- The date, time, and shift for each entry

This makes it easy to go back and check previous work, compare results between shifts, or just keep a record of everything you've done.

To ensure that the development of the desktop-based application aligns with actual user needs and research objectives, a Requirements Traceability Matrix (RTM) has been developed, as shown in Table 2. This matrix establishes a clear link between each functional component of the application (e.g., login, calculation, dashboard) and the corresponding research questions (RQ1–RQ4). By tracing each feature back to specific research goals, the matrix demonstrates how user requirements were systematically integrated into the design. This approach enhances methodological transparency and reinforces the user-centered design philosophy by ensuring that all functionalities directly contribute to addressing the defined research problem.

Table 2. Requirements Traceability Matrix linking application features to user requirements.

Requirement ID	Requirement Description	Implemented Feature	Design Justification
REQ1	Automate cone counting to reduce errors	Cone Calculation Interface + Algorithm	Uses figurative numbers to automate counting precisely
REQ2	Generate reports for managerial use	Excel Export Function (Openpyxl)	Enables tangible output for tracking and reporting
REQ3	Monitor individual worker activity	User Authentication & Logging	Links calculations to specific users via login credentials
REQ4	Real-time analytics and productivity dashboard	Dashboard Tab	Displays shift summaries and usage stats dynamically

3.4 User Acceptance Testing (UAT)

To evaluate the effectiveness of the application's functionality, we designed and conducted User Acceptance Testing (UAT). This testing strategy ensures that the cone counting desktop application meets functional requirements and delivers seamless user experience in yarn manufacturing settings. UAT involves manual testing by end-users, such as operators and supervisors, to verify usability, validate requirements, and assess the application's ability to handle edge cases effectively.

Process:

- **Planning:** Establish UAT scope and objectives with stakeholders' input.
- **Test Case Development:** Create test cases based on user workflows and requirements.
- **Execution:** Users perform test cases, logging any discrepancies or feedback.
- **Feedback and Iteration:** Analyze issues raised and refine the application accordingly.

Example Test Case:

Table 3. Sample test case (TC-001) demonstrates cone calculation and data storage validation during UAT.

Test Case ID	TC-001
Description	Verify that a user can calculate and save the total number of cones correctly.
Preconditions	User must be logged in.
Test Steps	1. Launch the application and log in using valid credentials.
	2. Navigate to the Home tab and choose the appropriate yarn type.

Test Case ID	TC-001
	<p>3. Input the following:</p> <ul style="list-style-type: none"> • Stack Height = 5 (an odd number) • Center Front Cones = 10 • Cones on the Other Side = 8
	4. Click the "Calculate" button to compute the total number of cones.
	5. Save to Excel: Click the "Save to Excel" button to store the result in the history file (history.xlsx).
Expected Result	The system accurately computes and displays the correct total number of cones, and the result is successfully saved in history.xlsx.
Actual Result	As expected, the correct calculation is displayed, and the data is saved into history.xlsx.
Status	Passed

By implementing this comprehensive UAT strategy with a well-defined process, detailed test cases, and iterative improvements, the project ensures that the desktop application is robust, reliable, and meets the real-world needs of its users. This ultimately supports improved accuracy and efficiency in the manual cone counting processes within the yarn manufacturing industry.

3.5 Iterative Enhancement: Language Customization Feature

After the initial User Acceptance Testing (UAT), we employed interface evaluation techniques to aggregate customer feedback and improve the user experience for workers who found the application difficult to use in English. To address this, we

introduced a language customization feature that enables users to switch the interface language to Urdu. This option is available in the Settings section of the top navigation bar (see Figure 11). When Urdu is selected, core components of the interface including navigation labels, instructions, and error messages are displayed in Urdu (Figure 12).

3.5.1 Context of Use in User Interface Evaluation

The interface design was informed by the ‘context of use’ framework, which emphasizes the dynamic relationship between the user, their tasks, and the software system, all situated within an organizational, technical, and physical environment” (Kent & Williams, 1996). This model served as the foundation for aligning our design enhancements with real-world work scenarios and user capabilities.

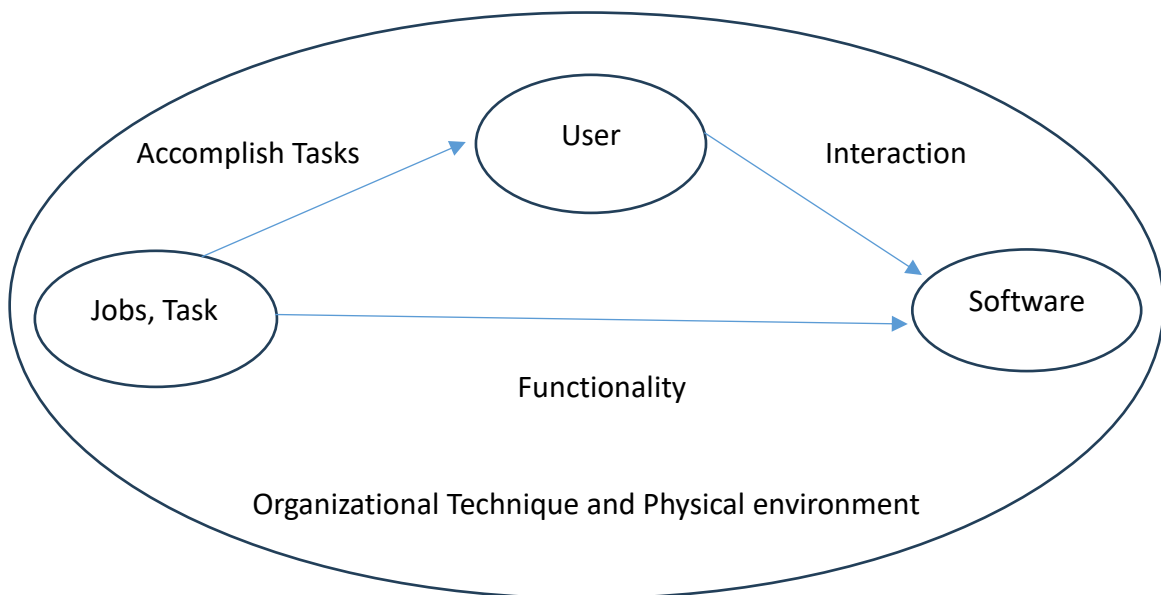


Figure 13. Context of use: elements to be considered during the evaluation of usability. *Adapted from Kent & Williams, 1996.*

3.5.2 Iterative Prototyping and Feedback Integration

Our design process followed an iterative prototyping approach, where user feedback was collected, analyzed, and implemented in multiple cycles. Each cycle informed refinements to the interface design and functionality. As recommended by Kent &

Williams (1996), this approach ensured that user needs and usability issues were systematically addressed.

The following table outlines the key iterations and resulting enhancements

Table 4. Iteration and Enhancements.

Iteration	Feedback Source	Key Insight	Action Taken
1	Initial UAT	Users struggled with English-only interface	Urdu language option introduced
2	Heuristic Evaluation	Inconsistent terminology and layout for Urdu text	Standardized terminology and adjusted layout for right-to-left language
3	Cognitive Walkthrough	Users had difficulty locating the language toggle	Relocated the toggle to a more visible area in the Settings menu

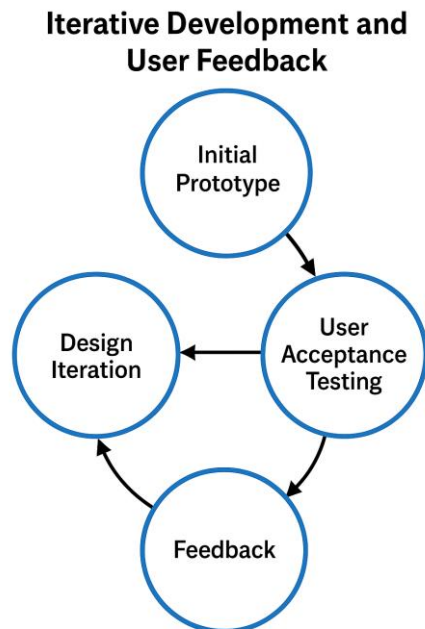


Figure 14. Iterative Development and Feedback Loop.

Figure 14 illustrates the user-centered, cyclical design process adopted in the study. Beginning with an initial prototype, the system was refined through repeated cycles of user testing, feedback collection, and design iteration.

Interface Evaluation Methods

Two usability evaluation strategies were employed to refine the interface: heuristic analysis and simulated user interaction (Torrente et al., 2012). The former helped identify issues in terminology and layout, while the latter tested ease of navigation and discoverability.

- **Heuristic Evaluation:** Based on Torrente et al. (2012) ten usability heuristics, we conducted expert reviews to detect problems related to consistency, visibility of system status, and user control Torrente et al. (2012). This led to improved language consistency and interface alignment for Urdu.
- **Cognitive Walkthrough:** We simulated new user behavior to evaluate ease of learning and navigation. This revealed that users struggled to find the language option, leading us to reposition it for better visibility.

Annotated Interface Screenshots

To support these evaluations, we included annotated screenshots:

- **Figure 11:** Shows the Urdu language toggle in the Settings menu. Annotations highlight improved positioning and visibility.
- **Figure 12:** Depicts the interface after Urdu is selected, with annotations on translated elements and layout adaptation for right-to-left text.

These visual annotations provide analytical insight into usability decisions and improvements made through each iteration.

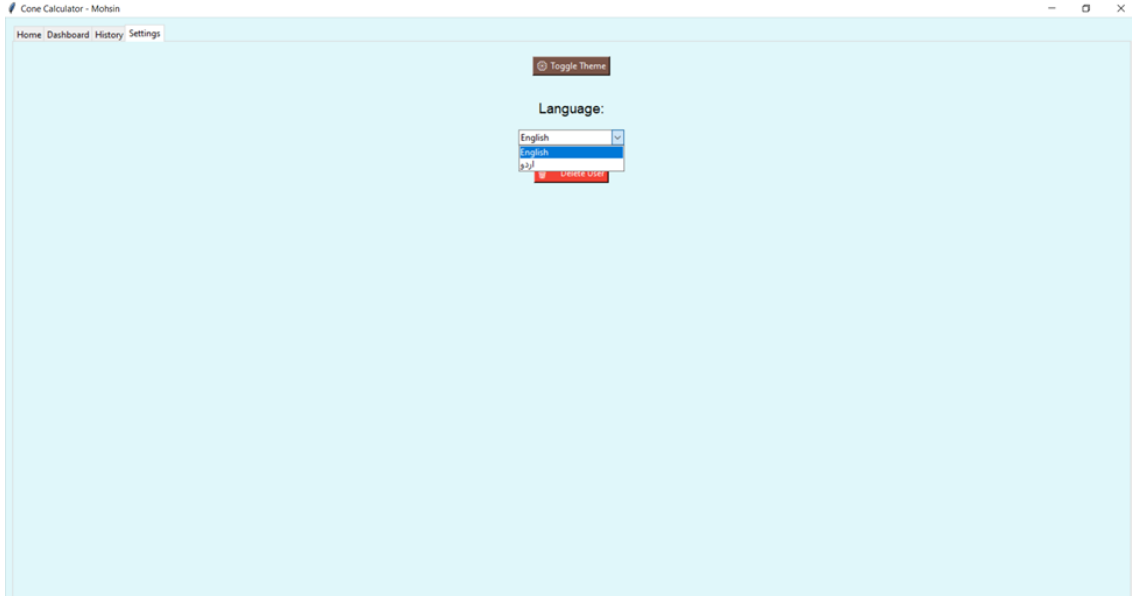


Figure 15. Settings screen showing the language customization option in the Cone Counting Application.

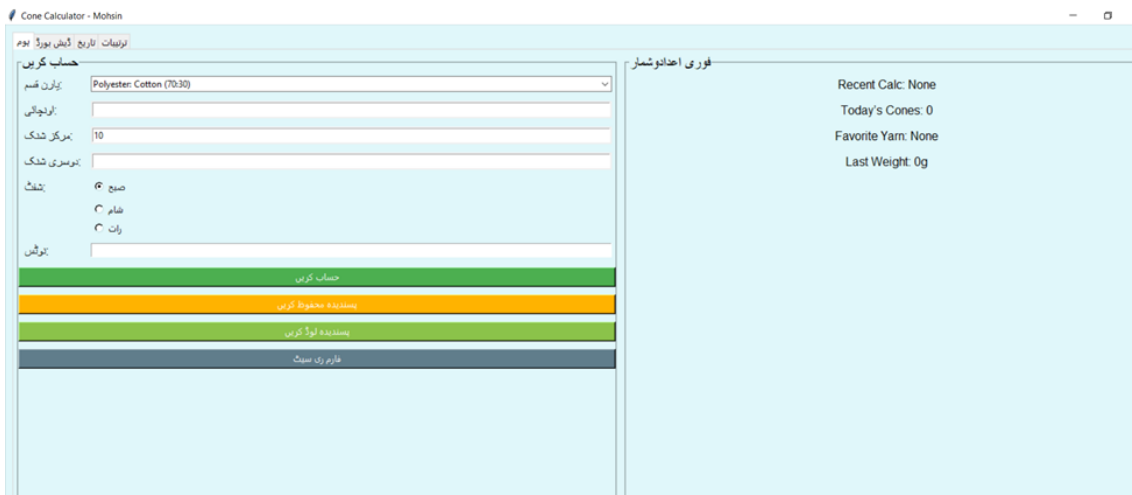


Figure 16. Application interface after language customization to Urdu, improving usability for non-English-speaking workers.

3.6 Evaluation

This study adopts the Research Onion framework by Saunders et al. (2023), which supports structured methodological decisions to align research tools with study objectives. This model provides a systematic approach for choosing the appropriate methods and tools for evaluation and validation of a research, ensuring alignment between research objectives and methodological choices. The following components as shown in figure 11 have been selected that suit the nature and objectives of our research:

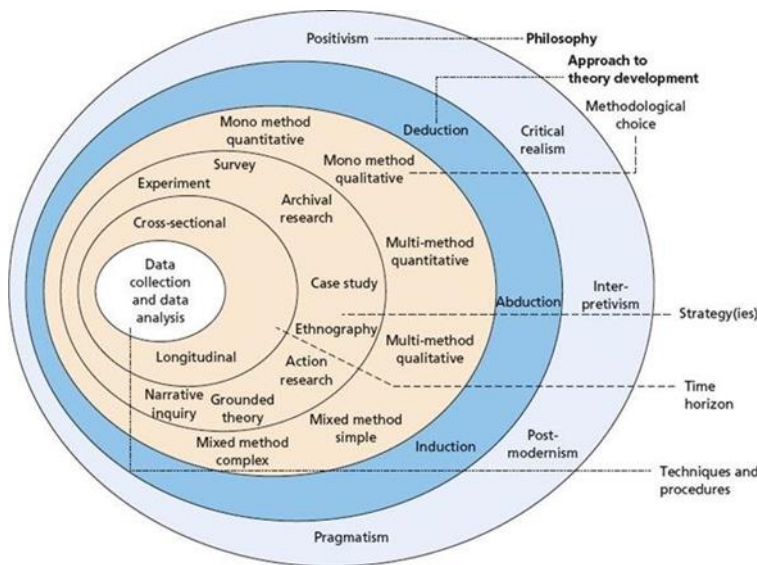


Figure 17. Research Onion (Saunders et al., 2023).

3.6.1 Cross-Sectional Data

We collected data at one specific point in time, right after the app was rolled out and workers were trained. This cross-sectional approach let us get a quick snapshot of how the app was performing in its early days. We gathered feedback and data from workers across different shifts morning, evening, and night to see how the app held up in the real-world chaos of a factory. The focus was on figuring out how much the app improved accuracy, sped up workflows, and kept users happy, all within a short timeframe.

3.6.2 Mono Method

A mono-method quantitative strategy was applied using standard deviation to measure the consistency and reliability of cone counts before and after the application implementation. This let us compare how consistent cone counts before the app (when workers counted manually) and after (when they used the app). A lower standard deviation in the app's counts meant fewer mistakes and more reliable data. By focusing on this single metric, we could clearly see if the app was making a measurable difference in reducing human error.

3.6.3 Inductive Approach

This research follows an inductive approach, allowing user experiences and observations during testing to shape the understanding of the application's performance, letting the workers' experiences guide us. We paid close attention to what users said and how they used the app during testing. For example, early on, we noticed a lot of workers struggled with the English-only interface. So, we added language customization to make the app more accessible. This flexibility, listening to users and tweaking the app based on their real needs was central to our process.

3.6.4 Philosophy: Pragmatism

This research embraces a pragmatic philosophy, emphasizing the development of a solution that delivers tangible value to users rather than theoretical ideals. The primary objective was to create a tool that improves accuracy, saves time, and reduces user effort in real-world textile operations. That meant focusing on practical wins: cutting down on counting errors, saving time, and making data entry less of a hassle. By keeping our eyes on what would help workers in the real world, we ensured the app was useful and user-friendly.

Based on this approach, we will use data analysis to quantitatively assess the improvements in accuracy, efficiency, and user satisfaction, providing clear evidence of the application's impact in a real-world manufacturing environment.

3.6.5 Statistical Analysis

To strengthen the analysis, inferential statistical methods were applied. To evaluate the effectiveness of the application, paired sample t-tests were conducted, comparing the mean time and error rates before and after implementation. This approach aligns with standard statistical evaluation practices in usability studies (Creswell & Creswell, 2018). The t-test compares the mean of the differences and determines the probability that any observed effect is due to chance. A significance level of $\alpha = 0.05$ was used.

In addition, 95% confidence intervals were calculated to estimate the range within which the true mean difference lies. Confidence intervals were calculated to assess the statistical reliability of results. An interval excluding zero indicates a statistically significant difference meaning the observed effect is not likely due to chance (Moore, McCabe & Craig, 2017).

4 Results and Discussion

This chapter presents the key findings and analysis resulting from the evaluation of a custom-developed desktop application aimed at improving the cone counting process in a yarn production environment. The study adheres to the methodological framework outlined in Chapter 3, employing a cross-sectional approach to assess the application's efficacy against traditional manual counting practices. The chapter is segmented into four principal sections: Data Collection, Data Analysis, Results and Findings, and Evaluation. Together, these sections explain the application's performance across accuracy and efficiency metrics.

The dataset for this study was collected from a yarn manufacturing company in Pakistan and represents production data recorded across three work shifts: Morning, Evening, and Night over a single day.

The production process focuses on different types of polyester-cotton blend yarns (product types: 70:30, 52:48, 60:40, and 80:20), with each product handled by specific winding machines. Winding machines are the final stage in the yarn production process, where the finished yarn is wound onto paper cones. Each machine is equipped with sensors that automatically update an information display showing the total number of cones produced during each shift.

However, not all cones produced are considered high quality. Some cones are classified as B-Grade due to issues like damaged paper cones or improper yarn winding (e.g., yarn being wound too loosely). These B-Grade cones are recorded separately.

Actual production figures are obtained by deducting the quantity of B-grade cones from the machine-displayed total, ensuring that only high-quality outputs are considered in the final count. This adjusted figure provides a more accurate measure of production efficiency and product quality per shift.

The data across the three shifts (Morning, Evening, Night) were recorded separately, allowing analysis of production trends, machine performance, and product quality over a full production day. The collected production data is summarized in Table 3.

Table 5. Actual Production Report.

Shift	ProductType	Machine No.	Total Number	B - Grade Cones	Actual Production
Morning	PC (70:30)	Winding Machine01	817	5	812
	PC (52:48)	Winding Machine02	1115	9	1106
	PC (60:40)	Winding Machine 03	783	3	780
	PC(80:20)	Winding Machine 04	850	0	850
Evening	PC(70:30)	Winding Machine 01	941	3	938
	PC(52:48)	Winding Machine 02	1232	4	1228
	PC(60:40)	Winding Machine 03	797	7	790
Night	PC(70:30)	Winding Machine 01	847	0	847
	PC(52:48)	Winding Machine 02	1029	0	1029
	PC(60:40)	Winding Machine 03	726	1	725

Data on the cone counting process was gathered using both manual techniques and the desktop application, facilitating a direct performance contrast. The recorded variables include:

- **Worker User ID:** Unique identifier for the worker performing the count.
- **Shift:** The shift during which counting took place (morning, evening, or night).
- **Product Type:** The specific polyester cotton blend counted.
- **Counting Method:** Indicates manual or application-based counting.
- **Number of Cones Counted:** The worker's recorded count using the chosen method.
- **Actual Number of Cones:** The verified production total for accuracy validation.
- **Time Taken for Counting:** Duration of the counting task, in minutes.

- **Mistakes:** A binary flag denoting counting error

Table 6. Comparison of time taken and mistakes using manual counting versus the application across three shifts.

User Id	Shift	Product Type	Counting Type	No of Cones	Actual Cones	Time Taken for Counting	Mistakes
WR0001	M	PC(70:30)	Manual	812	812	8 min	0
WR0001	M	PC(70:30)	App	812		3 min	0
WR0001	M	PC(52:48)	Manual	1009	1106	7.5 min	1
WR0001	M	PC(52:48)	App	1106		3.5min	0
WR0001	M	PC(60:40)	Manual	780	780	10 min	0
WR0001	M	PC(60:40)	App	780		2.3 min	0
WR0001	M	PC(80:20)	Manual	850	850	3.45 min	0
WR0001	M	PC(80:20)	App	850		1.20 min	0
WR0002	E	PC(70:30)	Manual	938	938	6.3 min	0
WR0002	E	PC(70:30)	App	938		2 min	0
WR0002	E	PC(52:48)	Manual	1228	1228	9.3 min	0
WR0002	E	PC(52:48)	App	1224		3 min	1
WR0002	E	PC(60:40)	Manual	790	790	5.2 min	0
WR0002	E	PC(60:40)	App	790		1.3 min	0
WR0003	N	PC(70:30)	Manual	847	847	10 min	0
WR0003	N	PC(70:30)	App	847		3 min	0
WR0003	N	PC(52:48)	Manual	1029	1029	13 min	0
WR0003	N	PC(52:48)	App	1029		4 min	0
WR0003	N	PC(60:40)	Manual	725	725	4.3 min	0
WR0003	N	PC(60:40)	App	725		2 min	0

For instance, during the morning shift, Worker WR0001 manually counted 1009 cones for PC (52:48), while the actual output was 1106 cones, revealing an undercount. Conversely, the application accurately recorded 1106 cones for the same batch. This dual-method data collection was consistently applied across shifts and product types, ensuring a comprehensive dataset.

The collection process was tailored to reflect authentic operational settings, accounting for variables such as worker differences, shift conditions, and product intricacies. This design bolsters the findings' applicability to real-world manufacturing scenarios.

4.1 Data Analysis

The analysis focuses on two key performance indicators accuracy and efficiency, to objectively compare manual and application-based counting methods.

Accuracy Analysis

Accuracy was measured by computing the standard deviation of discrepancies between actual cone counts and those recorded by each method per product type. A lower standard deviation signifies higher precision and fewer deviations from the true totals.

The accuracy outcomes, measured by standard deviation, are detailed in Table 5.

Table 7. Standard deviation of cone count errors for manual and application-based methods.

Product Type	Total Actual Count	Total Manual Count	Total Count by App	Standard Deviation (Actual vs Manual)	Standard Deviation (Actual vs App)
PC(70:30)	2597	2597	2597	0	0
PC(52:48)	3363	3266	3359	68.58935778	2.83
PC(60:40)	2295	2295	2295	0	0
PC(80:20)	850	850	850	0	0

- PC (70:30):** Actual production totaled 2597 cones (812 morning, 938 evening, 847 night). Both manual and application counts aligned perfectly with this total, yielding standard deviations of 0 for both methods, indicating impeccable accuracy.
- PC (52:48):** Actual production was 3363 cones (1106 morning, 1228 evening, 1029 night). Manual counts summed to 3266 cones (1009 + 1228 + 1029), with a standard deviation of 68.59, reflecting variability due to an undercount in the morning. Application counts totaled 3359 cones (1106 + 1224 + 1029), with a standard deviation of 2.83, showing a slight deviation in the evening (1224 vs. 1228).

- **PC (60:40):** Actual production was 2295 cones (780 morning, 790 evening, 725 night). Both methods recorded 2295 cones, resulting in standard deviations of 0.
- **PC (80:20):** Actual production was 850 cones (morning shift only). Both methods accurately reported 850 cones, with standard deviations of 0.

These results highlight that, except for PC (52:48), where manual counting faltered, the application consistently matched or exceeded manual accuracy.

4.1.1 Efficiency Analysis

To assess efficiency, the total duration required for cone counting was measured across different product types and worker shifts, comparing manual versus application-assisted methods.

A detailed comparison of manual and application-based methods is presented in Table 6:

Table 8. Time Efficiency.

Worker ID	Shift	Time for Manual Counting	Time for App Counting	Gap
WR001	M	28.95	10	18.95
WR002	E	20.8	6.3	14.5
WR003	N	27.3	9	18.3

- **Worker WR001 (Morning Shift):** Manual counting took 28.95 minutes (8 + 7.5 + 10 + 3.45), while the application took 10 minutes (3 + 3.5 + 2.3 + 1.2), saving 18.95 minutes.
- **Worker WR002 (Evening Shift):** Manual counting required 20.8 minutes (6.3 + 9.3 + 5.2), versus 6.3 minutes (2 + 3 + 1.3) with the application, saving 14.5 minutes.

- **Worker WR003 (Night Shift):** Manual counting took 27.3 minutes (10 + 13 + 4.3), compared to 9 minutes (3 + 4 + 2) with the application, saving 18.3 minutes.

The application reduced counting time by an average of 17.25 minutes per shift, a consistent efficiency gain attributed to automated processing and reduced manual effort.

4.1.2 Statistical Significance Testing

To evaluate whether the observed differences in time and error between the manual and application-based counting methods are statistically significant, paired sample *t*-tests were conducted. These tests assess whether the mean difference between the two methods is likely due to chance.

Table 9. T-tests and p-values.

Comparison	Mean Difference	t(df)	p-value
Time-to-count (min)	17.25	t(2)=12.43	0.003205
Error magnitude (cones)	23.25	t(3)=1	0.195501

For time-to-count, the result is statistically significant with a p-value of 0.0032, indicating a reliable reduction in counting time when using the app compared to the manual method. In contrast, the difference in error magnitude is not statistically significant, with a p-value of 0.1955, indicating that the observed reduction in error may not be consistent across all scenarios.

4.1.3 Confidence Intervals

To quantify the precision of the observed differences, 95% confidence intervals were calculated for both measures:

Table 10. Statistical Significance Testing.

Comparison	95% CI Lower	95% CI Upper
Time-to-count (min)	11.27	23.22
Error magnitude (cones)	-50.74	97.24

The 95% confidence interval for the time-to-count improvement was [11.28, 23.22] minutes, confirming a consistent benefit across shifts. For error magnitude, the CI was [-50.74, 97.24], which includes zero, suggesting that the error reduction may be variable.

4.2 Results and Findings

Following the Research Onion's inductive approach, the findings are derived directly from the data, allowing patterns to emerge naturally. The results show both the application's strengths and the context where manual counting remains effective.

For PC (70:30), PC (60:40), and PC (80:20), both manual and application-based methods achieved perfect accuracy, with standard deviations of 0 across all shifts. This suggests that manual counting is reliable for lower-volume or simpler tasks, where workers can maintain focus. However, for PC (52:48), with a total of 3363 cones, manual counting showed significant variability. The standard deviation of 68.59, driven by a 97-cone morning undercount (1009 vs. 1106), indicates errors in high-volume scenarios. The application, with a standard deviation of 2.83 and a discrepancy of 4 cones. (1224 vs. 1228), demonstrated greater consistency.

Efficiency results are consistent across shifts. The application reduced counting time by an average of 17.25 minutes per shift, with savings of 18.95 minutes (morning), 14.5 minutes (evening), and 18.3 minutes (night). This reduction reflects the application's ability to automate calculations and data entry, streamlining the process.

Key findings include:

1. **Improved Accuracy for Complex Tasks:** The application demonstrated superior accuracy in high-volume scenarios, such as PC (52:48), by significantly minimizing human counting errors compared to manual techniques.
2. **Significant Time Efficiency:** The 17.25-minute average time saving per shift enhances operational productivity.
3. **Minor Application Errors:** The 4-one evening error suggests a need for minor adjustments in the application or user training.

While the average time saving of 17.25 minutes per shift may seem small on its own, the impact becomes much more significant when considered on scale. For example, if this time is saved across three shifts a day, five days a week, that adds up to around 215 hours saved each month for a single worker. Multiply that by 10 workers, and you're looking at over 690 hours saved every month time that could be used to improve other areas of production, reduce overtime, or ease workload pressure.

High accuracy in tasks involving large quantities such as with PC (52:48) translates to reduced error rates and minimized rework, ultimately conserving operational time and resources (Shingo, 1986). However, small discrepancies like the one observed during the evening shift show that even automated tools still need some human oversight or minor adjustments. This also points to the importance of proper training when introducing new technology on the shop floor.

Overall, these results suggest that while the application doesn't replace human skill, it complements it well especially in fast-paced or high-volume settings. It also highlights the need to think about digital literacy and training as part of any move toward more automated systems in production environments.

4.3 Evaluation

In this section we evaluate the desktop application's capability to enhance the cone counting process in a yarn manufacturing facility with the aid of the pragmatic focus of the Research Onion on practical solutions. The study's contributions, missing gaps, and recommendations for future improvements are drawn from the evaluation of the application. The system successfully delivers on the dual objectives of accuracy and efficiency, supporting the study's goal to streamline the cone counting process in textile operations. It significantly reduces errors, especially for high-volume products like PC (52:48), where manual counting was inconsistent. Accurate counts are needed to ensure reliable inventory records that are important to good production planning and low waste. Automating the task of counting saves an average of 17.25 minutes per shift for workers to take up other tasks like inspecting yarn quality and maintaining equipment. This would lead to an improvement in productivity as well as reducing operational costs. Furthermore, it is also possible to reduce the mental burden on workers by automating a repetitive task, though it is necessary to subject it to further exploration through feedback studies targeted at users. Nevertheless, the application has limitations that need to be addressed. A small error in the evening shift for PC (52:48), where it recorded 1224 cones instead of 1228, suggests issues with either user input or the application's processing. These challenges highlight the importance of error-proofing (Poka-Yoke) features already integrated into the application (Shingo, 1986). Features such as validation checks for correct inputs (e.g., odd-number-only height entry), and structured input fields have significantly reduced the potential for user mistakes during data entry an approach consistent with Lean Six Sigma practices. This indicates a need for improved error-checking features or better training for workers. The study's focus on a single day's data also restricts its ability to evaluate long-term performance. Factors like varying production demands or worker familiarity with the application could influence results over time, and a one-day dataset cannot capture these dynamics. While workers reported the application as easy to use, there is room to enhance its interface, such as by adding more intuitive error alerts or supporting additional languages to accommodate diverse staff.

To improve the application, several steps are proposed. First, strengthening data validation, such as requiring confirmation for unusual entries, could prevent errors like the one observed. Second, a longer study spanning multiple days or weeks would clarify the application's reliability across different conditions. Third, collecting regular input from workers could guide interface refinements, ensuring the application meets their needs effectively. For example, clearer notifications or expanded language options could make it more user-friendly.

The developed desktop application demonstrated superior performance over manual methods in cone counting by improving both accuracy and efficiency. These benefits contribute to improved reliability and workflow in yarn manufacturing operations. With minor technical adjustments and extended evaluation, it could further streamline factory processes and serve as a template for technological improvements in similar manufacturing settings.

5 Conclusions

This study aims to get rid of the ever-existing problem of inefficiency and inaccuracy in the textile industry.

The proposed solutions are as follows.

- Development of a unique cone counting algorithm that will be rooted in the notion of figurative numbers.
- Integration of the algorithm into a desktop-based desktop application that will facilitate the workers having limited English skills by providing an Urdu interface
- High levels of accuracy and efficiency can be achieved by using a computerized cone counting process.

This will save at least 17 minutes per shift that will translate into considerably huge financial gains if seen time saved across multiple shifts and over months and years. This will mean more inventory control and better management. Accuracy will mean more costs being saved by avoiding counting related errors. This would also mean that there will be smoother production flow as there will be no need for rework or verification.

The research adds greatly to the world knowledge of mathematics and in terms of devising a relation between number theory and industrial cones counting management. It goes on to show how the highly abstract concepts of mathematics can provide a physical and measurable practical solution in the sphere of textile industry.

The proposed solution for the desktop-based application is going to be very cheap and user friendly and it is going to bring a lot of efficiency. This might be very attractive to the industries that are not fully automated yet.

5.1 Managerial Implications and Recommendations

This study presents outcomes such as improving time, labor, and accuracy. The immediate one is operational efficiency that can be leveraged by the managers as 17 minutes per shift can be looked upon as a substantial improvement in the management and the top leaders can strategically deem it to be a huge financial gain. Over the years, this saved time can be used instead of maintenance, quality assurance, or skill-building activities, as these are often overlooked due to time constraints.

The industry can adopt the solution proposed by the study by using this in the high-volume activity so that the effect could be noticeable and the advantage can be measured immediately. Nevertheless, there might be workers not adept at using computer in their day to day activity. Therefore, some workers might need training to use this desktop-based application in their routine work. It may also need some integration of this tool into the existing inventory tracking system to be able to use it at its maximum capacity.

5.2 Future Research Consideration

One very interesting future related aspect of this research could be an AI-enabled vision system that would count the cone in real time by camera vision and image processing. Moreover, it will be worth looking to improve the algorithm so that it will be incorporated to help count the inventory of different shapes or stacked together differently. An additional notion of future prospect would be to improve the communication system within the industry so that any changes in the inventory could be immediately counted, recorded and communicated to update the inventory tracking system. In a nutshell, the future aspects are more than one and the solution proposed by this could be expanded in a variety of ways to make it even more useful in the industry.

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