

UTILISING DATABASE MANAGEMENT SYSTEMS AND STATISTICAL PROCESS CONTROL TO ELEVATE QUALITY ASSURANCE FOR AGRICULTURAL PERISHABLES

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ABSTRACT

Inefficiencies within agricultural packhouse operations undermine both quality assurance and profitability. However, to address the inefficiencies, the following industrial engineering tools are developed in this study: a decision support system (DSS) that leverages the power of database management systems (DBMS) and statistical process control (SPC). This industry-wide solution transcends the limitations of isolated data and reactive quality control. The DSS captures real-time operational data by seamlessly integrating a robust DBMS with Excel and Power BI, identifying previously hidden insights. Advanced SPC algorithms analyse this data, providing insight into dimensions of defect patterns and process variability. This study contributes towards literature and the entire agricultural industry by following a data-driven revolution in quality assurance. The proposed framework offers a blueprint for potential integration across diverse operations, fostering a paradigm shift towards proactive, data-driven quality control.

Keywords: citrus packhouse operations, decision support system, quality inefficiencies, operational inefficiencies, defect identification

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1 INTRODUCTION: BACKGROUND AND INTRODUCTION

The Citrus Agriculture and Processing Industry in South Africa has experienced significant expansion over the past decade. 2010, the industry covered 56,338 hectares, growing to 86,808 hectares by 2019 [1]. One of the main factors contributing to this growth is the export of fresh citrus fruit, which has contributed significantly to the industry's increasing revenue. Packhouses are a crucial section of the citrus industry as they are responsible for arranging, grading, and packaging the fruit according to market requirements. The demand for fresh citrus fruit remains high worldwide throughout the year, which demands a continuous supply of high-quality produce [2]. Given the industry's growth and the critical role of packhouses, it becomes a priority to improve operational efficiency and quality control procedures continuously. Addressing the challenges faced by packhouse operations and quality inefficiency will contribute to the industry's continued growth and enhance the quality of South African citrus as a premium product in the global market.

Company-X, which will be used as a case study, is a leading citrus exporter in the country and operates three packhouses that sort, grade, and pack citrus fruits for export to international markets. The citrus production and packing company were established over one hundred years ago. Production primarily focuses on the high-value export market. It concentrates on a diverse citrus basket that includes seeded and seedless lemons, Valencia types such as Turkeys, Midnight, Delta, and late Valencia variations, as well as other citrus kinds [3].

A citrus packhouse's purpose is to maintain the quality of the fruit received from the orchards while preparing it for export. This involves cleaning the fruit, treating it to prevent the development of postharvest diseases, enhancing its appearance and shelf-life, sorting it into size and class categories, and packaging it according to market requirements [4]. The packhouse is a crucial component of the citrus industry, where various operations are conducted to ensure the quality and efficient packaging of the fruit.

These operations involve various tasks, starting with fruit sorting, where trained personnel carefully examine each fruit and separate them based on their characteristics, such as size, colour, and appearance. Following sorting, the fruit goes through a grading process, where it is categorised based on specific quality standards, such as external appearance, blemishes, and internal attributes. After grading, the fruit is prepared for packing, where it is carefully placed into boxes, considering factors like weight distribution, packaging materials, and labelling requirements. During these operations, quality procedures ensure that only the highest quality fruit is selected for packaging. This involves conducting quality checks and adhering to strict standards to meet export market requirements.

The company aims to produce as many classes 1 and 2 fruits as possible for the export market. The highest drop from the potential output to the actual production documented in the season was more than 37%, and a significant loss in export output potential. These daily losses of the potential production are due to uncalculated and unforeseen defects only discovered after the fruit has been tipped in the packhouse. **Figure 1** shows the potential loss in daily output due to packhouse operational and quality inefficiencies.

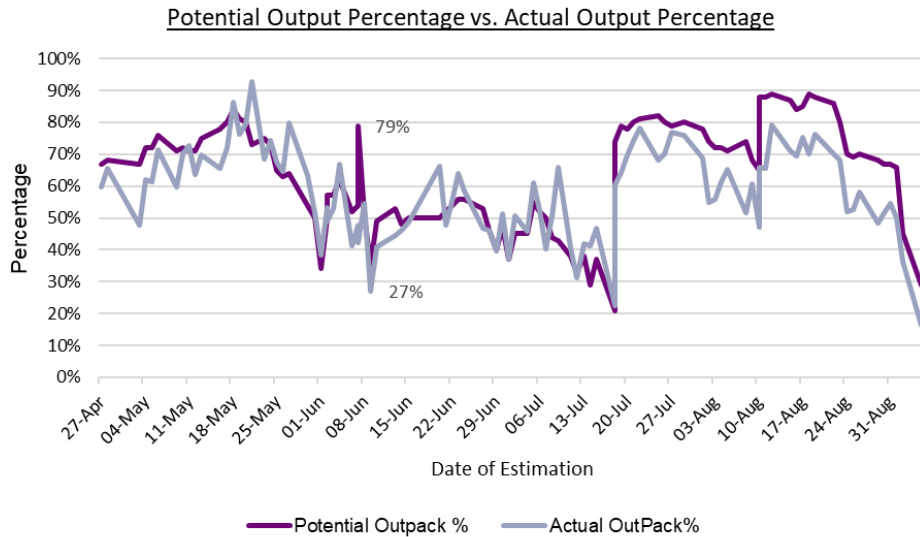


Figure 1: The loss in daily output potential due to packhouse operational and quality inefficiencies.

The decrease in potential pack-out for Company-X is due to the following identified inefficiencies: Insufficient Fruit Quality, Suboptimal Resource Allocation, Suboptimal Packing Pattern, and Time to Identify Issues. Based on the background, the packhouse operations are experiencing operational and quality inefficiencies, posing significant challenges to overall performance and final product quality.

This study aims to address the operational and quality inefficiencies in the citrus packhouse by developing a DSS. The project scope includes the citrus packhouse operations and quality procedures, particularly those involving human decision-making. These include preparation of daily operations, fruit sorting, grading, packing, quality checks, and addressing identified quality defects.

A systematic literature review (SLR) conducted by Van Der Merwe et al. [5], which is the first part of this study, includes a comprehensive and systematic search of existing scholarly literature on a specific topic to provide an overview of the current state of knowledge, identify research gaps, and inform the development of research questions and objectives. The SLR investigated existing research and identified gaps in agricultural quality procedures within citrus packhouses. Focusing on four research questions, the review analysed 33 relevant studies from databases such as Science Direct, Scopus, Web of Science, EBSCO Host, and Emerald Insight. These studies covered various aspects of packhouse operations, including data analytics, industry 4.0, lean management, and quality control. The findings demonstrated diverse quality procedures, systems, and technologies in packhouse operations. The review provides valuable insights into the current state of research, emphasising the significance of data analytics, industry 4.0, lean management, and quality control in optimising packhouse operations for citrus production. Future research in this field should explore integrating these approaches and technologies to develop comprehensive and efficient quality procedures within packhouse operations. It would be beneficial to investigate these approaches' effectiveness and practical implementation challenges, supporting industry practitioners and researchers. In conclusion, the SLR identified a range of quality procedures, systems, and technologies used in citrus packhouses. This knowledge can guide future research and facilitate continuous improvements in quality procedures within agricultural packhouses.

The paper is outlined as follows. The research method is explained in Section 2. A current state and a root cause analysis are conducted in Section 3, followed by a concept design in Section 4. The development of the system is demonstrated in Section 5, followed by the

verification and validation in Section 6. Conclusions and future recommendations are provided in Section 7.

2 RESEARCH METHOD

For the project approach, the waterfall methodology was utilised. A waterfall methodology is a project approach where all requirements are gathered at the beginning of the project, and then a sequential project plan is created to accommodate those requirements [6]. The outline of this method is demonstrated in **Figure 2**.

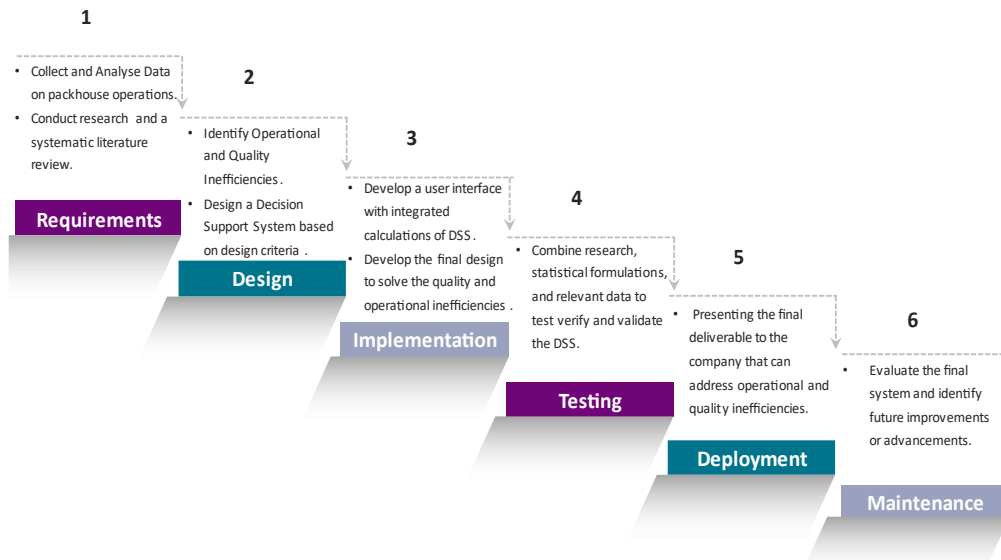


Figure 2: The Waterfall Methodology Project Approach Followed

Figure 2 illustrates the Waterfall Methodology; each stage is designed to ensure a systematic and structured progression toward the successful completion of the project. These stages include:

- 1. Requirements:** Case studies and a SLR referred to in Section 1 are conducted to enhance the research process further.
- 2. Design:** Once the operational and quality inefficiencies have been identified, the project will develop accurate and data-driven solutions.
- 3. Implementation:** After the system's conceptual design is developed in Section 4, the project is evaluated, and the most suitable alternative based on predetermined decision criteria is chosen.
- 4. Testing:** The research findings, calculations, and relevant data are integrated and implemented to conduct solution verification in the system.
- 5. Deployment:** The verification and validation are completed, and the final design is presented and validated in Section 6.
- 6. Maintenance:** The project does not conclude with the design of the deliverable. A thorough evaluation will be conducted to assess the effectiveness and performance of the system in Section 6. Additionally, any potential areas for improvement and future recommendations will be identified and addressed.

3 THE CURRENT STATE AND ROOT CAUSE ANALYSIS

3.1 Current state analysis

The current state analysis provides valuable insights into the existing processes and quality procedures, allowing the identification of inefficiencies in the packhouse's operations and

quality procedures. **Figure 3** illustrates the defects influencing the reduction in fruit quality received by the packhouse from the orchards [3].

Entomological defects:	Climatological defects:	Plant disease defects:	Physiological defects:	Defects due to insufficient Picking discipline:
<ul style="list-style-type: none"> •Red Scale •Bladder early •Bladder Leave •Bollworm •Surveyor •Tortrix •Mealybug •Mealybug present •Page Jumper •VKM/Carob Moth •Mites 	<ul style="list-style-type: none"> •Hail •Sunburn •Wind 	<ul style="list-style-type: none"> •Black Spot •Melanosis •Alternaria •Greening •Sooty mold •Spoiled 	<ul style="list-style-type: none"> •Cracked Shell •Oleo •Cracked Fruit •Malformed fruit •Cracked Peel •Chemical burn •Off Season •Color 	<ul style="list-style-type: none"> •Tear out stalks •Long stems •Picking injuries

Figure 3: Categories of defects influencing the decrease in fruit quality.

The defects are classified into several categories. By identifying these specific defect categories, the packhouse managers can focus on addressing each defective category and enhancing overall fruit quality. The packing time throughout the day is demonstrated in **Figure 4**. The data in **Figure 4** is calculated from extensive time and motion studies.

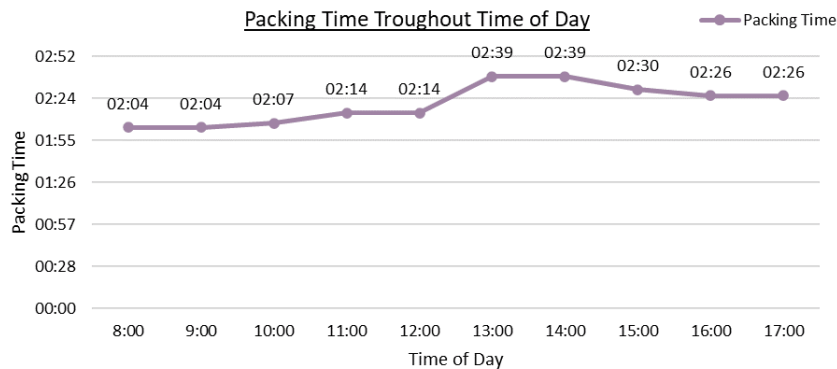


Figure 4 shows that the maximum average cartons packed by one packer with the current average speed is twenty-three cartons per hour.

3.2 Root cause analysis

In this section, a comprehensive analysis of the citrus packhouse operations and quality procedures is conducted to address the root cause of the operational and quality inefficiencies. Various industrial engineering tools, including time and motion studies, the Ishikawa Diagram, and the 5-Why analysis, are utilised to achieve this analysis successfully.

The 5-Why analysis from Section 3.1 enables a systematic approach to identify the root cause of the operational and quality inefficiencies. By repeatedly asking "why" and delving deeper into the underlying factors contributing to each problem, insights are gained into the fundamental causes of inefficiencies. The results are demonstrated in **Figure 5**.



Figure 5: 5-Why Analysis of Company-X

The root cause analysis suggests a need for a systematic approach to identifying and addressing defects in the packhouse. This absence of a structured problem-solving process contributes to difficulties in identifying defects as they occur, leading to delayed defect resolution. Additionally, there appears to be a lack of data-driven decision-making, postponing the ability to make informed decisions based on real-time data. The Ishikawa diagram in Figure 6 provides a structured way to identify and display potential causes of a specific problem or effect.

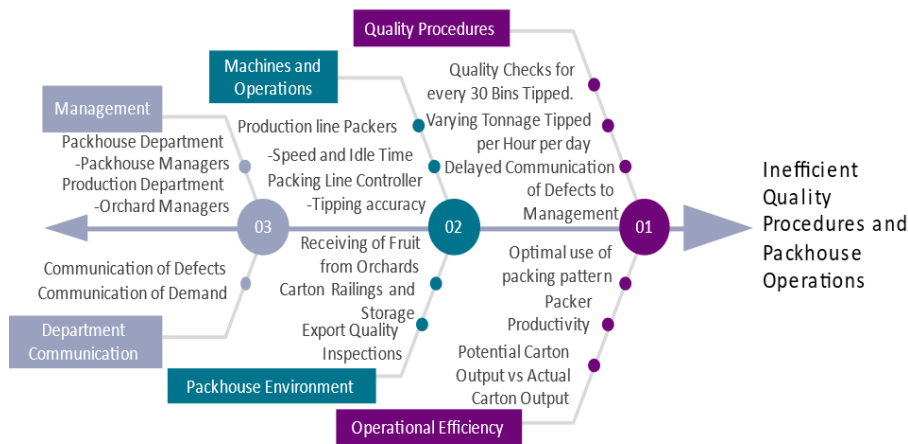


Figure 6: Ishikawa Diagram of Company-X

Figure 6 is utilised to understand various sections of the company and what their influences may be on the quality procedures as well as their influences on packhouse operations. Analysing the Ishikawa diagram, 5-Why Analysis, and the information gained during a Gemba walk and comprehensive time and motion studies, the identified root cause highlights the absence of data-driven decision-making and a systematic approach within the quality control procedures and packhouse operations. This implies that the packhouse's management lacks access to real-time data and comprehensive insights, leading to suboptimal decision-making regarding quality procedures and operational inefficiencies. Furthermore, the identified root cause highlights the absence of data-driven decision-making and a systematic approach within the quality control procedures and packhouse operations.

4 CONCEPT DESIGN

4.1 Conceptual Requirements and Decision Criteria

The following design requirements are essential to determine the DSS's conceptual design. These include but are not limited to budget limitation, simplified implementation, user-friendly interface, resource efficiency, and readiness. **Table 1** presents the decision criteria derived from the conceptual design requirements. The priority of these criteria is also determined to ensure that those with the highest importance have the most significant influence on the software selection for DSS design.

Table 1: Decision Criteria and Prioritisation

Decision Criteria	Priority	Description
User Familiarity	High	The software should be recognisable to the users at Company-X to minimise the learning curve and ensure quick adoption of the DSS.
Decision-Making Capabilities	Medium	The software should have advanced decision-making capabilities, including optimisation algorithms and analytical tools, to enhance packhouse operations.
Data Handling Capabilities	Low	The software should be capable of handling and processing large volumes of data generated during daily operations, ensuring efficient data management and analysis.
Cost-Effectiveness	High	Cost-effectiveness is crucial, and the software should have minimal to no additional costs to adhere to the budget limitations.

The seamless integration with Power BI enhances data visualisations, enabling management to gain comprehensive insights. Excel and VBA programming, accompanied by Power BI, offers a cost-effective, user-friendly, and efficient solution for Company-X's DSS needs.

The research done by Van Der Merwe et al. [5] provided valuable insights into various quality procedure concepts suitable for developing and designing Company-X's DSS. Based on the findings and considering the specific requirements of Company-X, implementing two concepts is recommended to establish the company's systematic and data-driven approach towards quality control.

4.2 Design Requirements

The design requirements for Company-X's DSS must be developed to provide a comprehensive design for the final solution. The input, output, and user interface requirements are developed to ensure seamless integration and functionality with the system's chosen software. This approach embraces Microsoft Excel [7], presenting a solution that corresponds well with the company's design requirements.

4.2.1 Input Data Requirements

The DSS will be used through daily manual input of quality and operational parameters to aid decision-makers in making informed decisions based on comprehensive insights. The DSS receives manual input data through its user interface, encompassing qualitative and quantitative attributes, as shown in **Table 2**.

Table 2: Quantitative and Qualitative Input Data Attributes

Data Category	Quantitative Attributes	Qualitative Attributes
Operational Data:	Tonnes Tipped for the day and Available Production Hours	Packhouse ID
Quality Data:	Quality Check Type and Fruit Type	Identified Deficiencies and Quality clerk ID
Packaging Data:	Count Type, Desired Weight and the Average Weight of Fruit for Specific Size	Fruit Type
SPC Data:	Tonnes Tipped and Confidence Interval	Fruit Type
Report Generation Data:	Email of Quality Report Receiver	

4.2.2 User Interface Requirements

The user interface of the DSS for Company-X's packhouse operations is a critical aspect of its effectiveness and usability. The user interface should be user-friendly and visually insightful, facilitating seamless interaction between the user and the DSS.

The User Interface consists of the following aspects:

1. **Input Section:** This section allows users to input data manually. Users should be able to update and modify the input data as needed quickly. The system's technical design will include Macros and Buttons for user input possibilities.
2. **Scenario Selection:** The users can choose specific scenarios based on changed input data, such as defects, production volumes, or changes in fruit types.
3. **Optimisation Settings:** Users can customise optimisation settings, such as labour allocation and quality confidence intervals, to align the system with Company-X's operational requirements.
4. **PowerBi Visualisation Tools:** Interactive charts, graphs, and dashboards enable users to visualise the impact of different decisions on packhouse operations, aiding in better decision-making.

The following Excel sheets, as seen in **Figure 7**, which include Macros, Buttons and User Form Generations, are applicable to the DSS design.

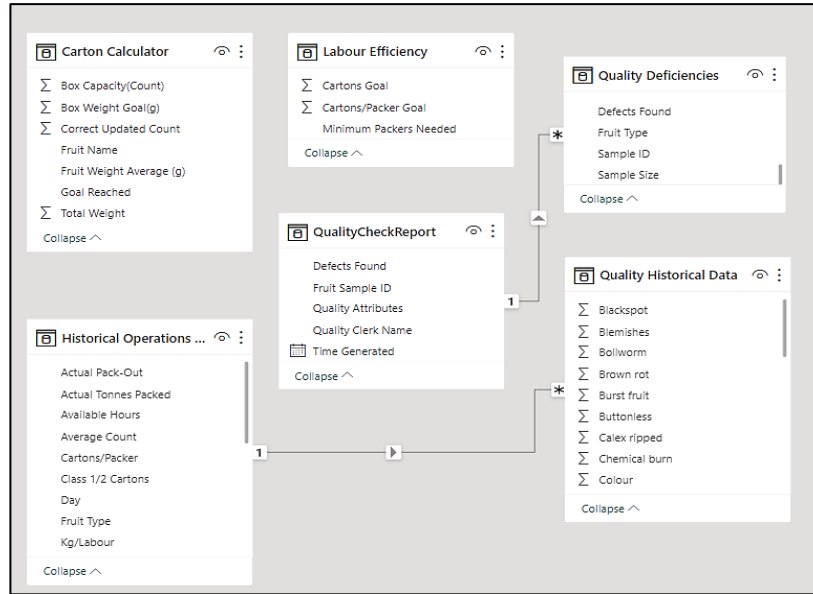


Figure 7: Data Layout of Excel Sheets

The user interface provides a clear and comprehensive overview of defect mitigation possibilities by utilising calculations created through Visual Basic Programming and interactive dashboards created in Power BI [8]. This enables decision-makers to quickly grasp the current state of operations and identify operational or quality inefficiencies that require immediate addressing. With intuitive visuals, real-time data updates, and real-time communication, the User Interface becomes a value-adding aspect, facilitating informed decision-making.

4.2.2.1 Macro Formulations

A vital aspect of the system is ensured by formulating calculations within the macros, all of which are established in predetermined data or manual inputs.

- **Resource Utilisation:** determines the minimum number of packers needed to achieve a daily packing goal, improving the utilisation of resources and providing a cost-saving solution through reduced labour costs. The suggested number of cartons a packer should be able to pack per hour is 23.
- **Sample Size Calculation:** determines the optimal sample size according to the amount of tonnage tipped in the packhouse and a Confidence Interval as selected by the packhouse managers.

A Statistical Quality Control formula determines the sample size to achieve a specific confidence level and margin of error while considering the available tonnes tipped [9]. By incorporating these calculations within the DSS, the system transforms manual input data into actionable insights, aiding decision-makers in enhancing packhouse operations and quality procedures.

4.2.3 Output Data Requirements

The deliverable's output data should be designed to be comprehensive and assist as a valuable aid to decision-makers at Company-X in their efforts to enhance the efficiency of packhouse operations and quality control procedures. Ensuring the robustness of the output data is essential, as it directly influences the credibility and reliability of the decision-making process. The output data includes the following aspects:

- **Quality Control:** The system can monitor real-time quality parameters during packing using computer vision systems and sensors. If any deviations from the quality standards are detected, the DSS will provide real-time alerts to the decision-maker.

- **Quality Insights:** The DSS can analyse past quality data and identify insights on fruit quality. It will provide insights to the decision-maker on how to take preventive actions and start mitigation strategies.
- **Performance Evaluation:** The DSS can measure the performance of each packhouse based on key performance indicators such as throughput, defect rates, and resource utilisation.
- **Quality Check Reports:** Automatically generated reports that can be emailed to relevant stakeholders, providing comprehensive real-time insights into daily operations, deficiencies, and quality performance. These reports provide detailed information about the defects identified at the quality checks.
- **Packout Potential Analysis:** Comparative analysis is provided of the potential pack out versus the actual pack out, highlighting the efficiency of the packhouse operations.
- **Optimal Quality Checks Sample Size:** Recommendations for the appropriate sample size based on the tonnage tipped and specified confidence level.
- **Data Export:** Formatted data that can be easily exported to external formats for further analysis and decision-making.

The DSS will be able to be a real-time decision-making tool, providing timely and data-driven decision-making possibilities to enhance packhouse operations and quality control procedures. The output data generated by the DSS demonstrates a robust and effective solution to address the identified root cause in **Section 3**.

4.3 Data Preparation and Analysis

Data preparation is a fundamental process that involves collecting, cleaning, and organising data from various sources to ensure its suitability for analysis and decision-making [10]. The aim is to gain valuable insights from the data that will provide an effective solution for the packhouse's operational and quality inefficiencies.

4.3.1 Historic Data Preparation

Figure 8 includes the steps followed for the historic data preparation approach.



Figure 8: Data Preparation Process

The DSS consists of comprehensive and reliable data to support data-driven decision-making and improve packhouse operations and quality procedures by following this approach.

4.3.2 Input Data Validation

The input data will undergo thorough validation checks to identify potential errors or inconsistencies. If any discrepancies are detected, the system immediately generates error notifications, prompting users to correct the issues before proceeding.

To further enhance data accuracy, the User-friendly interface guides users through the data entry process, providing clear instructions and prompts. Dropdown menus, predefined options, and input constraints are employed to restrict the entry of incorrect or inappropriate data. This design approach streamlines the input process and reduces the risk of human errors.

5 THE DECISION SUPPORT SYSTEM DEVELOPMENT

5.1 Introduction to Final Design

The following section outlines the updated operations and quality procedures that the DSS will follow. **Figure 9** illustrates the Business Process Mapping Notation of the DSS's use by the users, namely packhouse management and quality controllers. This ensures a seamless integration of existing processes within the DSS [11].

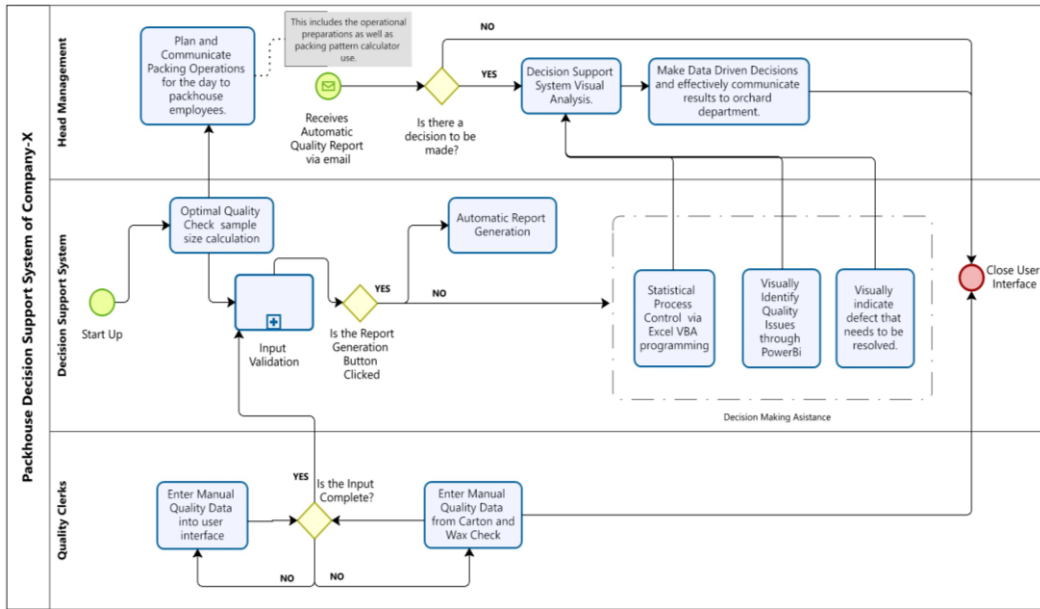


Figure 9: Business Process Mapping Notation of the added DSS.

Figure 10 illustrates the improved packhouse quality process flow with the added DSS.

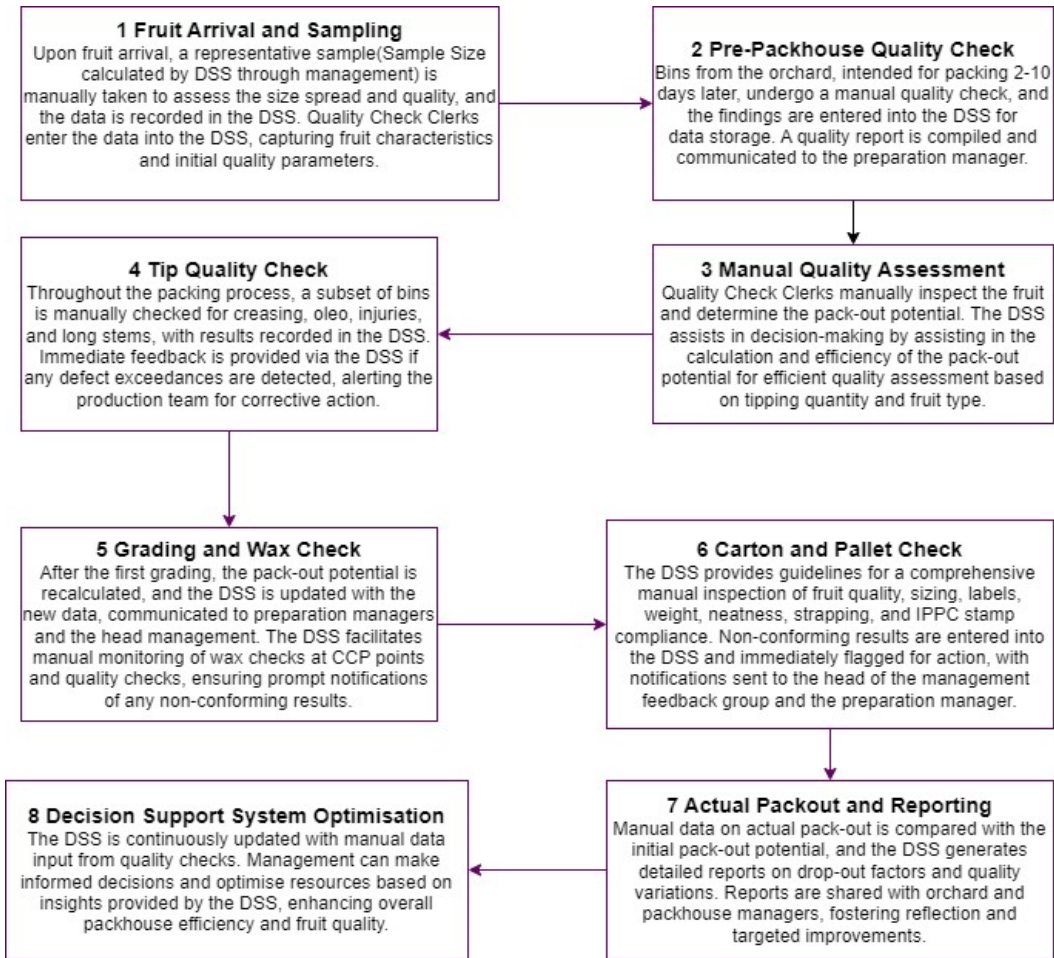


Figure 10: Improved Packhouse Quality Control Process flow with the added DSS

Appendix A demonstrates the final design interphase of the DSS.

6 SYSTEM VERIFICATION AND VALIDATION

6.1 Verification of system design

The system design has been verified by evaluating it against the decision criteria and design requirements established in Section 4. The verification process forms part of the testing phase of the Waterfall Methodology project approach. This verification is confirmed in Table 3.

Table 3: Verification of Solution's adherence to design requirements.

Design Requirements.	Question to determine if the system adheres to the specified design requirements.	Explanation of Adherence.
The system should adhere to the budget limitations.	Does the system require additional costs for the company?	No. Leveraging Excel and Visual Basic Programming entails no additional costs for the company, as existing licenses fully support system utilisation.
The system should enable	Is the system complex enough to implement	The system is not complex to implement within the current operations and quality

simplified implementation.	within the current Packhouse Operations and Quality Procedures?	procedures. Including a user manual simplifies the implementation while using familiar software known to the Packhouse Manager further facilitates the implementation process. The additional quality procedures are easily integrated with the current Quality Checks.
The system should consist of a user-friendly interface.	Is the system complex to use?	No. The system's interface is user-friendly, offering easy use through manual input and straightforward button operations for calculations. Additionally, data input is rigorously controlled through Excel data validation and dropdown lists, minimising the potential for incorrect manual inputs.
The system should demand minimal additional resources.	Does the system demand additional resources?	No. The system requires minimal demands for additional resources. The only new software required is Power BI, which shares the exact licensing requirements as Excel. Consequently, no extra resources are needed, ensuring cost-efficiency in implementation.
Seamless integration with existing software should be ensured.	Will the system struggle to integrate with existing software in the packhouse?	No. The company's current utilisation of Excel is leveraged to ensure the smooth integration of the additional Excel-based system. Furthermore, Power BI effortlessly integrates with Excel. This compatibility reduces any operational or procedural disruptions during implementation.
The system should include future adaptation possibilities.	Will the system be challenging to adapt to future changes?	No. The system is designed with flexibility, allowing for straightforward adjustments to accommodate daily preparations and changing operational goals. Additionally, the Power BI system seamlessly adapts to the data it receives. Thus, defects encountered during the current season and future season possibilities are displayed.
The system should include manual input capabilities.	Will the users struggle to input data manually?	No. The system displays a user-friendly interface that simplifies manual input, catering to Packhouse Managers and Quality Clerks. The design streamlines the input process, improving overall usability.
The system should enable the visual interpretation of results for Packhouse Managers.	Will the system's results be unable to be visually interpreted?	No. The system's refined data collection processes seamlessly integrate with Power BI, facilitating comprehensive visual interpretations of results. These dynamic visuals empower Packhouse Managers to effectively communicate defect-related insights to Orchard Managers for targeted mitigation strategies.

<p>The system should ensure minimal time consumption for Quality Clerks.</p>	<p>Is the system time-consuming for quality clerks to use?</p>	<p>No. The system's Quality Report Generation feature significantly reduces time consumption for Quality Clerks. With manual input capabilities and user-friendly dropdown lists, generating defect reports becomes automated. By simply pressing a button, real-time defect reports are communicated to management. This aspect improves the efficiency of quality procedures.</p>
<p>The system should eliminate the possibility of human errors.</p>	<p>Does the system increase the likelihood of human errors?</p>	<p>No. The system eliminates the possibility of human errors during manual input. This is achieved through the rigorous implementation of strict Excel controls integrated into the system's design, allowing only accurate data entry. Users are promptly alerted to incorrect inputs and guided to make necessary corrections, ensuring data integrity and reliability.</p>

Company-X confirmed the above verification.

6.2 Validation of the systems packhouse preparation calculator to enhance operational efficiency and quality procedures

The Preparation Calculator significantly improves packhouse efficiency. It improves resource allocation, allowing for more carton packing with fewer packers; this can be seen in each scenario. This improvement reduces the cost of packhouse operations while improving efficiency and productivity. In **Table 4**, 579,3 Tonnes of Valencia's were tipped with an 80% pack-out potential.

Table 4: Validation Scenario 1

Production Parameter	Current State	Improved State (Potential State)	Improvement
Number of Packers	151	115	36 fewer Packers.
Cartons Packed	27730	27773	43 More Cartons Packed.
Sample Size (For every 30 Bins)	50	421(95% Confidence Level)	371 Sample Size Increases
Defect Exposure	1,67%	14,04%	12,37% more exposure to defects
Productivity	183,6424	241,5043	31,51% more efficient

This improved scenario can be seen in **Figure 11**.

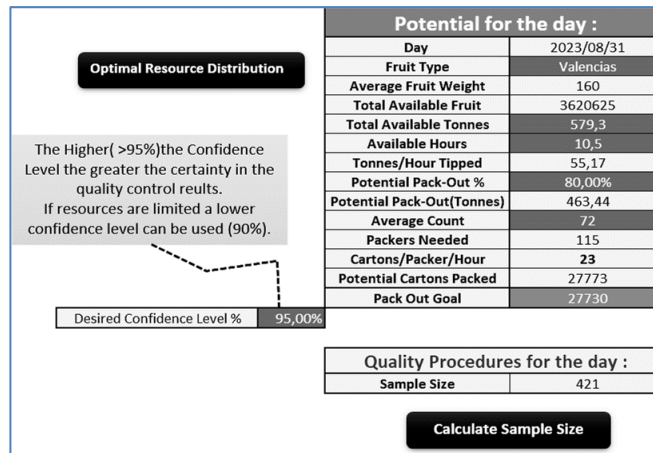


Figure 11: Scenario 1 Improved Results

There are 10,5 available production hours. The improvement after using the system's preparation calculator shows labour cost savings of R9 608,76 for the day's labour costs. Given that the minimum loan for South Africa is R25,42 per hour [12]. A productivity calculation [13] demonstrates that the solution improves current packhouse efficiency.

$$Productivity = \frac{Output}{Input} \tag{1.1}$$

$$Productivity Improvement \% = \frac{Improved Productivity}{Initial Productivity} \times 100 \tag{1.2}$$

In Table 5, 343.5 Tonnes of Lemons were Tipped with a 67% pack-out potential.

Table 5: Validation Scenario 2

Production Parameter	Current State	Improved State (Potential State)	Improvement
Number of Packers	168	59	There are 109 fewer Packers.
Cartons Packed	10580	10585	5 More Cartons Packed.
Sample Size (For every 30 Bins)	50	281 (95% Confidence Level)	231 Sample Size Increases.
Defect Exposure	1,67%	8,74 %	7,07% more exposure to defects.
Productivity	62,97619	179,4068	184,88% more efficient.

This improved scenario can be seen in **Figure 12**.

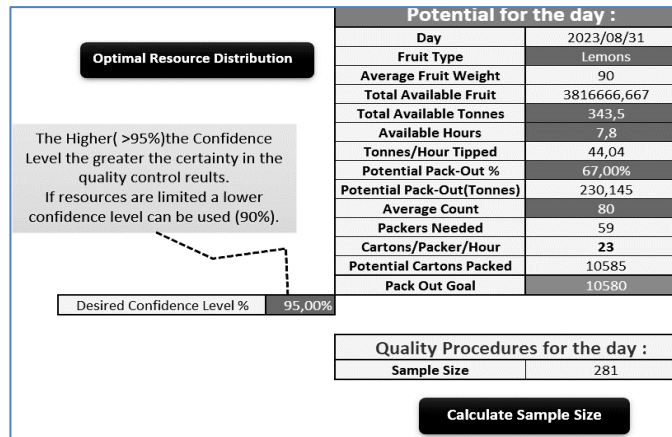


Figure 12: Scenario 2 Improved Results

There are 7,8 available production hours. The Improvement after using the system's preparation calculator shows labour cost savings of R21 612,08 for the day's labour costs. In Table 6, 55,8 Tonnes of Lemons-PH were Tipped with a 79% pack-out potential.

Table 6: Validation Scenario 3

Production Parameter	Current State	Improved State (Potential State)	Improvement
Number of Packers	163	25	138 fewer Packers.
Cartons Packed	1500	1553	53 More Cartons Packed.
Sample Size (For every 30 Bins)	50	54 (95% Confidence Level)	4 Sample Size Increases.
Defect Exposure	1,67%	3,6%	1,93% more exposure to defects.
Productivity	9,202454	62,12	575,01 % more efficient.

This improved scenario can be seen in Figure 13.

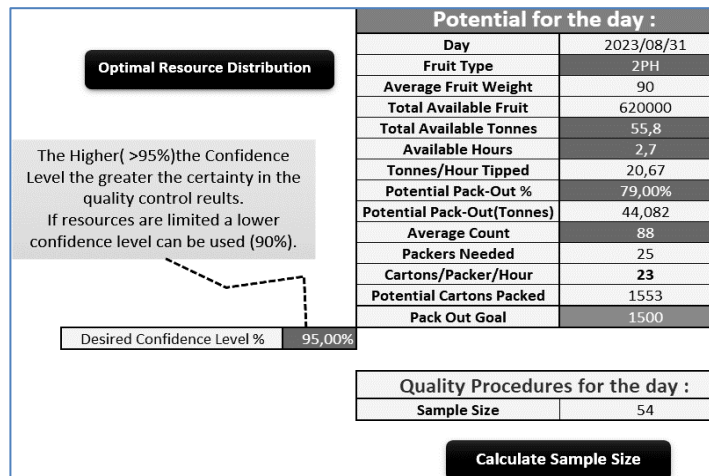


Figure 13: Scenario 3 Improved Results

There are 2,7 Available Production hours. The Improvement after using the system's preparation calculator shows labour cost savings of R9 471,49 for the day's labour costs. This is because 138 fewer packers are needed to reach the pack-out goal. The scenarios

demonstrate how the sample size is associated with the total tonnes tipped into the packhouse and the set confidence interval. Simultaneously, the number of packers necessary aligns with the management's pack-out goal.

7 CONCLUSIONS AND FUTURE RECOMMENDATIONS

In conclusion, the developed DSS enhances the quality procedures and operational efficiency of Company-X. It also comprises the capacity to improve other Citrus Packhouses. The following inefficiencies are successfully addressed: fruit quality, labour resource allocation, packing patterns and time to identify defects. The root cause of these inefficiencies, as determined in Section 2, which was the absence of data-driven decision-making and a structured approach to quality control procedures and packhouse operations, is subsequently addressed through the project's successful completion. The study's success and practical contribution additionally lie in providing packhouse management with real-time data and comprehensive insights to ensure informed decision-making. The DSS solves the operational and quality inefficiencies and positions the packhouse for sustained continual success and excellence in the citrus industry. If Company-X's budget limitation is excluded, it can be recommended that Company-X invest in tablet devices for quality controllers. Adding this feature would significantly improve their mobility and the efficiency of data collecting and reporting during the quality checks.

Future research opportunities may focus on further integrating DBMS systems and rigorous quality control principles within packhouse operations. This integration can further enhance decision-making capabilities, operational efficiency, and quality procedures. Future Research could examine the effectiveness of these approaches and address potential implementation challenges, offering valuable insights for agricultural industry practitioners and researchers. Establishing continuous improvement possibilities for this DSS could ensure that defects are accurately identified and addressed in various agricultural industries. They are additionally improving the standards of agricultural products in South Africa. This project's successful completion showcases its potential to improve quality procedures and operational efficiency. This information can be a foundation for future research and continuous enhancements in agricultural packhouse operations and quality procedures.

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9 APPENDIX A

9.1 Final Design Interface of Decision Support System

The following section represents the final design of the DSS's user interface, how the system improves Company-X's operational and quality procedures and its capacity for decision-making capabilities. **Figure 14** demonstrates the System Navigation Page, a critical component that improves both Packhouse Quality Procedures and Operational Efficiency.

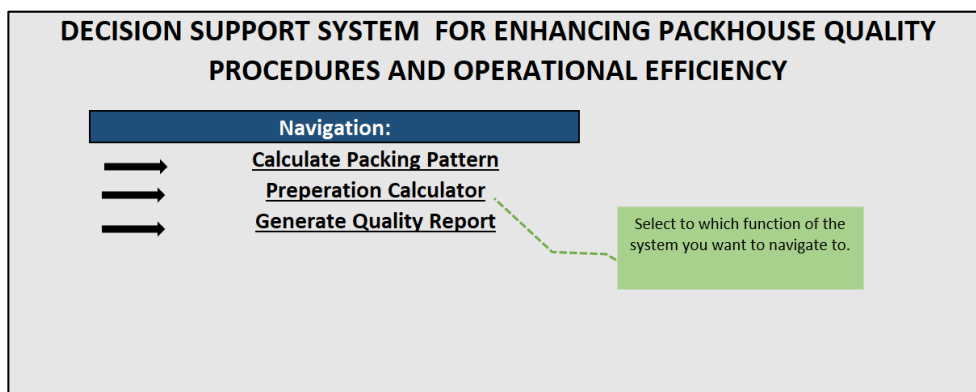


Figure 14: DSS Navigation Page

This page functions as the main portal for users, allowing them to easily access numerous system aspects such as the Packing Pattern Calculator, Packhouse Preparation Calculator, and Real-Time Report Generation for Quality Reports and Defect Data. The Navigation Page has

been designed to offer a user-friendly interface that ensures seamless, simple navigation. When users select the specific component they want to use, the system effectively transmits them to their desired page of the DSS, offering a simple but effective user experience. The green annotation on each page provides the steps to follow to use the system efficiently.

9.1.1 The Packhouse Preparation Calculator aspect of the system design.

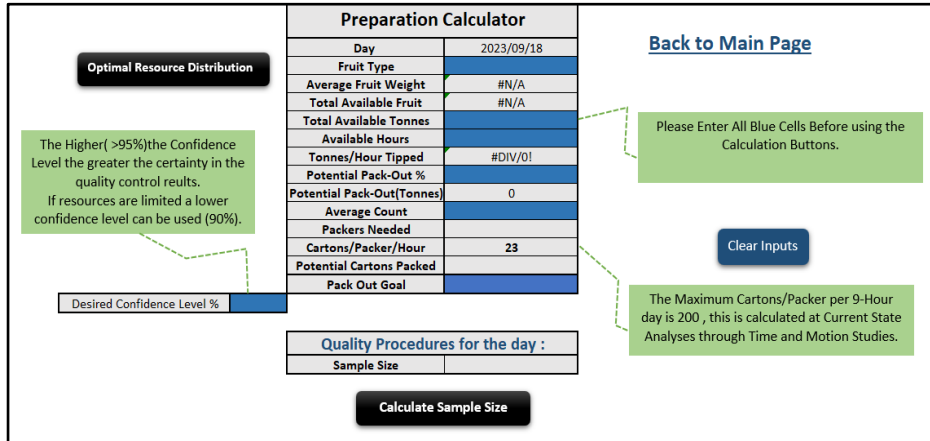


Figure 15: System's Preparation Calculator for Packhouse Management Use.

Figure 15 illustrates the DSS Preparation Calculator Page. This calculator is essential in supporting packhouse managers with decision-making, as well as improving overall efficiency, productivity, and resource utilisation throughout daily packhouse operations. It accomplishes this by estimating the minimum number of packers required to meet the day's pack-out goal efficiently. This estimate is based on time and motion study findings, which revealed an average packing rate of 23 cartons per hour per packer. While this value can be changed based on packhouse manager preferences, the anticipated rate of 23 cartons per packer per hour achieves ideal productivity.

To use this calculator effectively, the Packhouse Manager must fill in all values within the indicated blue blocks. After providing these parameters, the user can proceed by clicking the "Optimal Resource Allocation" button. Following that, the user can enter their preferred confidence interval before selecting the "Calculate Sample Size" button.

It is noted that a larger confidence interval improves the dependability of quality check results, allowing users more confidence that the results truly represent the defects present in the current tipping. It defines the sample quantity required for efficient quality control on the specified day. This computation is based on an established confidence interval and the total tipped tonnage for the day. The obtained sample size is the number of fruits that should be quality checked for every 30 bins, which corresponds to approximately every 3000 fruits. This defect identification can then be subjected to additional analysis to ensure that the correct defects are being addressed.

The email's content offers details about the quality control checks, offering insights into the fruit's quality. It includes details such as the date and time of the quality check, the particular quality controller and the type and amount of defects discovered. Furthermore, the email includes a personalised note, giving Quality Controllers the option to contribute additional context or insights.

By employing this automated email system, the packhouse ensures that critical defect data is communicated efficiently to decision-makers. This immediate communication allows for timely responses and informed decision-making, contributing to the overall quality of procedures' effectiveness and efficiency.

9.1.3 The Packaging Support Calculator.

Packaging Support Calculator							
Fruit Name	Fruit Weight Average (g)	Current Box Capacity(Count)	Total Weight	Box Weight Goal(g)	Goal Reached	Updated Count	Additional fruit needed
	#N/A		#N/A		#N/A	#N/A	#N/A
Back to Main Page						<input type="button" value="Clear Inputs"/>	
				This Calculator Aid's Descsion Makers to ensure the count(Pattern) associated with a specific Fruit Type will overall achieve the Weight Goal for each carton.			

Figure 18: Packaging Support Calculator for Packhouse Management Use.

Figure 18 illustrates the Packaging Support Calculator, a tool accessible to both Quality Controllers and Packhouse Management. Its purpose is to ensure that each final product meets the specified weight requirement. This is particularly critical for the export market, where compliance with weight standards is essential.

Firstly, the user should specify the fruit type for which the carton count pattern is being configured. After that, the current box capacity, which is user-defined based on the carton type currently in use, should be entered. The required weight for the carton should then be set. This is the maximum weight that each carton should attain. The calculator then calculates the overall weight of the carton by multiplying the average fruit weight by the box capacity selected. The system determines if the computed total carton weight is within the set weight range. If it is not, the calculator provides a modified count estimate as well as the additional amount of fruit required to achieve the weight goal. Users can then make informed decisions by picking the count that is nearest to the recommended adjustment.

The Packaging Support Calculator simplifies the process of verifying that cartons fulfil weight requirements consistently during quality checks. It removes the need for repetitive packing and weighing of cartons, making weight compliance more efficient and practical.

9.2 The System Integration with Power BI for result visualisation capabilities.

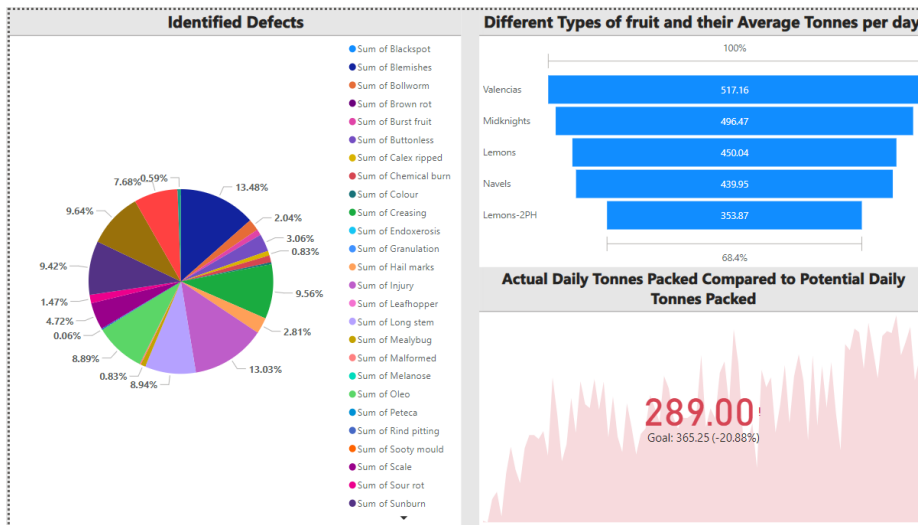


Figure 19: Power BI Dashboard for data visualisation.

Figure 19 illustrates the Power BI dashboard, a tool that decision-makers can use to improve their understanding of the packhouse’s quality performance and its influence on daily packing efficiency. This interactive dashboard has been developed to aid with data-driven decision-making and includes the following sections:

- Identified Defects:** This component uses a pie chart to illustrate discovered defects visually. Decision-makers can then promptly determine which defects are more significant.
- Fruit types and their average tonnes tipped per day:** The dashboard displays the numerous fruit varieties that were packed, along with their average daily tonnage. This data assists decision-makers in evaluating the performance of various fruit kinds in the packhouse.
- Actual vs Potential Daily Tonnes Packed:** This critical component compares actual daily tonnes packed to potential daily tonnes packed. Decision-makers can assess the effectiveness of daily operations by identifying any inconsistencies between actual production and the potential production of the packhouse.

The Power BI dashboard provides decision-makers with real-time insights on packhouse performance through a simple and information-packed interface. It allows them to make more informed decisions and prioritise defects that need to be addressed.

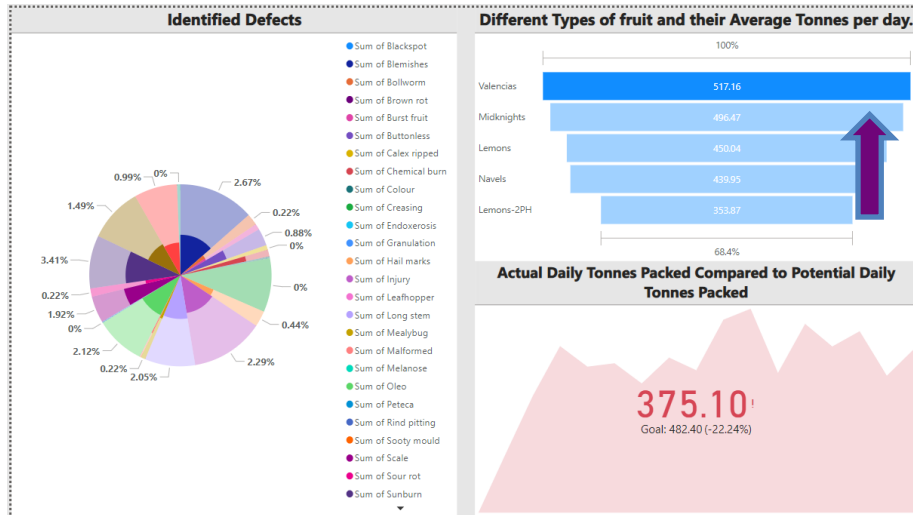


Figure 20: Power Bi Fruit Type Interaction.

Figure 20 demonstrates the interactive features of the Power BI dashboard, allowing Packhouse Managers to gain insights into the relationship between fruit types, defects, and their influence on daily tonnage loss. This visualisation enables Packhouse Managers to make informed data-driven decisions based on an accurate understanding of the influencing defects.

The dashboard provides an interactive interface that allows Packhouse Managers to examine how different fruit types are linked to certain defects; as seen in **Figure 20** by the purple arrow, a specific fruit is chosen. They can then identify which fruit types are more prone to specific defects by engaging with different combinations. The dashboard additionally demonstrates which fruit types are the most responsible for tonnage loss due to defects. This data is beneficial for strategic defect mitigation planning.

As a result, the Power BI dashboard is a valuable tool for Packhouse Managers to interactively investigate and fully understand the relationship between fruit types, defects, and their influence on daily tonnage packed. This insight enables managers to mitigate defects and improve the overall packhouse efficiency and final product quality, thus achieving the aim of the project as stated in Section 1.

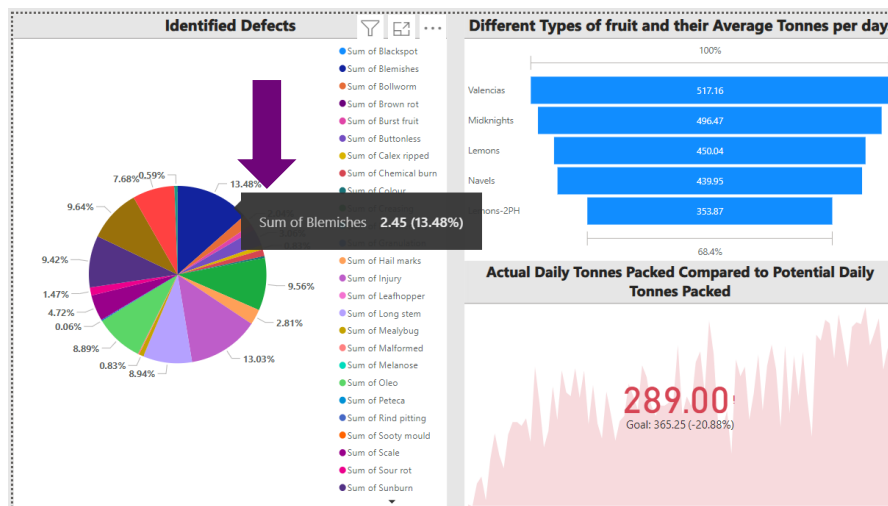


Figure 21: Power BI Defect Identification and Mitigation.

Figure 21 further illustrates the interactive features of the Power BI dashboard, providing Packhouse Managers with a more in-depth understanding of the impact of defects on pack-out losses.

Packhouse managers can pinpoint defects' influence on pack-out losses by simply clicking on them. This precision allows for accurate defect identification and mitigation. The dashboard illustrates the defects that have the greatest influence on pack-out losses based on the data given. Blemishes (13.48%), Injury (13.03%), Long Stems (8.94%), and Sunburn (9.42%) are examples from the current data used. Packhouse Managers may make informed decisions and prioritise which defects to address using this information. For example, resolving concerns like injuries and long stems may necessitate improved picking techniques, whereas minimising sunburn and blemishes may require the installation of extra netting in orchards.

Packhouse Managers are now able to collaborate with Orchard Managers to address specific defects and improve fruit quality, benefiting the overall packhouse operations. This is done by identifying and addressing high-impact defects. In addition, the citrus packhouse quality procedures and operational efficiency are enhanced.



Figure 22: Power Bi Defect Identification according to defect categories and fruit types.

Figure 22 illustrates an additional Power BI dashboard that offers a detailed overview of identifying defects by categorisation. This feature enables decision-makers to gain insights into where and how defects are distributed throughout different fruit types and their related categories, as established in Section 3.

The dashboard divides defects into categories, allowing decision-makers to differentiate between a variety of defects. This classification improves the accuracy of identifying defects. Decision-makers can investigate which fruit types are more prone to specific defect categories. The dashboard, for example, shows at the indicated purple arrow that Valencia's has the most severe instances of sunburn. This knowledge guides decisions on where to focus defect mitigation efforts. Decision-makers can now use this data to make data-driven decisions about how to address the defects. Based on the high incidence of sunburn in Valencia, for example, they can increase the amount of netting in Valencia's orchards as an immediate response. This systematic strategy guarantees that efforts are focused where they will have the most impact.

The Power BI dashboard provides decision-makers with a clear and structured overview of defects across different fruit types and defect categories. These data-driven insights allow for more informed decisions and more efficient use of resources, ultimately resulting in higher fruit quality and operational efficiency.