République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Ecole Nationale Polytechnique

المدرسة الوطنية المتعددة التقنيات
Ecole Nationale Polytechnique

EQUATORIAL COCA-COLA BOTTLING COMPANY

Département Maitrise des Risques Industriels et Environnementaux

Final Project Report for the Degree of State Engineer in QHSE-GRI

Interface Development for Advanced Pest Control

Study case: Equatorial COCA-COLA Bottling Company

Presented by: YAICI Rania

Supervised by:

Mme. S. BENTAALLA-KACED	Senior Lecturer	ENP
M. H. YOUSFI	Professor	ENP
M. Farid ADEL	National Quality Manager	ECCBC
M. Omar HAMDINI	Quality Manager	ECCBC

Presented and publicly defended on June 29, 2024, before the jury composed of:

Mr. M'hamed BOUSBAI	Senior Lecturer	ENP	President
Mrs. Marya FODIL	Assistant Professor	ENP	Examiner
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Département Maitrise des Risques Industriels et Environnementaux

Mémoire de Projet de Fin d'Études pour l'obtention du diplôme d'Ingénieur d'État en QHSE-GRI

Développement d'Interface pour le Contrôle Avancé des Nuisibles

Cas: Equatorial COCA-COLA Bottling Company

Présenté par: YAICI Rania

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Mr. Farid ADEL	National Quality Manager	ECCBC	Encadrant

ENP 2024

ملخص

تهدف هذه الاطروحة إلى تعزيز استراتيجيات إدارة الآفات المستخدمة من قبل ECCBC من خلال تقييم الامتثال لمعايير مكافحة الآفات لشركة كوكاكولا. يبدأ البحث بتقييم الإجراءات الحالية لتحديد فجوات الامتثال، يليه تحليل مفصل لمخاطر الآفات لتحديد المشاكل الرئيسية. يتمحور جوهر الدراسة حول تطوير نموذج تنبؤ وخوارزمية جديدة لتقييم المخاطر باستخدام عملية التحليل الهرمي (AHP) المنفذة من خلال واجهة تطبيقات (VBA) تدعم هذه الواجهة التقييم الديناميكي للمخاطر وإعداد التقارير المبسطة، مما يعزز قدرات اتخاذ القرار لإدارة الآفات بشكل استباقي وضمان الامتثال لمعايير سلامة الأغذية.

كلمات مفتاحية : إدارة الآفات, فجوات الامتثال, تقييم المخاطر, عملية التسلسل الهرمي التحليلي (AHP), الإدارة الاستباقية للآفات, (VBA) , الأمن الغذائي.

Résumé

Ce travail vise à améliorer les stratégies de gestion des nuisibles utilisées par ECCBC en évaluant la conformité aux normes Coca-Cola. L’évaluation des mesures actuelles de lutte contre les nuisibles pour identifier les lacunes en matière de conformité a été élaborée, suivie d'une analyse détaillée des risques de nuisibles pour identifier les problèmes clés. Le cœur de notre étude, consiste à développer un modèle de prédiction et un nouvel algorithme d'évaluation des risques utilisant le Processus de Hiérarchie Analytique (AHP). Cela a été mis en œuvre via une interface Visual Basic for Applications (VBA). L’interface soutient l'évaluation dynamique des risques et la génération de rapports simplifiés, améliorant ainsi les capacités de prise de décision pour une gestion proactive et garantissant le respect des normes de sécurité alimentaire.

Mots-clés : Gestion des nuisibles, Lacunes de la conformité, Évaluation des risques, AHP, Gestion proactive des nuisibles, VBA, Sécurité alimentaire.

Abstract

This work aims to enhance pest management strategies used by ECCBC by assessing compliance with Coca-Cola's pest control standards. It begins with an evaluation of existing pest control measures to identify compliance gaps, followed by a detailed pest risk analysis to pinpoint key problems. The core of the study involves developing a prediction model and a new risk evaluation algorithm using the Analytic Hierarchy Process (AHP), implemented through a Visual Basic for Applications (VBA) interface. This interface supports dynamic risk evaluation and streamlined reporting, thus improving decision-making capabilities for proactive pest management and ensuring adherence to food safety standards.

Keywords: Pest Management, Compliance gaps, Risk Evaluation, AHP, decision-making, VBA, Food Safety.

Dedication

“

I dedicate this humble work

To my beloved parents, who have supported me from day one and still…. May God bless you with health, prosperity, and a long, happy life.

To my Hocine and Nada, thank you for letting me keep the light on late at light.... You are my silent champions;

To my dear husband, Mohamed, you are my inspiration and rock;

To my grandparents, you will always be in my heart…

To my friends, you have lightened the heavy days like comforting tea before exams. Your laughter and companionship are a blessing;

To my family, your love and pride keep pushing me to do better;

I am so grateful for you all; I love you.

Finally, to myself, thank you for never giving up, even when life threw MDF on you. May Allah bless our knowledge “and make us leaders of the Muttaqoon” [al Furquaan 25:74]

“

Now, onto the next chapter, because how hard could it be?

Acknowledgement

I start by thanking ALLAH the Almighty for giving me the courage and patience to complete this work.

My heartfelt thanks to my supervisors Mrs. S. BENTAALLA, Mr. H. YOUSFI, and Mr. F. ADEL for the time they have dedicated, the advice they have given, and their invaluable assistance in successfully completing this work.

My thanks also go to Mr. O.HAMDINI, plant quality manager, and Mr. F.TEBIB, Metrology & Quality Monitoring Manager for giving me the opportunity to access the documentation, answering my questions and giving me feedback during my internship.

Special thanks to our committed alumni, MAREF Kaouther, for helping me not only in this internship but also throughout all the study years.

I extend my sincere thanks to Mr. M. BOUSBAI, who has honored us by presiding over the jury, and to Mrs. M. FODIL and Mr. M. SENOUCI BEREKSI, for agreeing to examine this thesis.

A special thought to all the teachers of the MRIE Department and to my classmates, who have provided me with their moral and intellectual support throughout this thesis.

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List of Abbreviations

ACF	Autocorrelation Function
ADF	Augmented Dickey-Fuller
AHP	Analytic Hierarchy Process
AIC	Akaike Information Criterion
AR	Autoregressive
ARIMA	AutoRegressive Integrated Moving Average
BCE	Before Common Era
BIC	Bayesian Information Criterion
ECCBC	Equatorial Coca-Cola Bottling Company
FDA	Food and Drug Administration
FSSC	Food Safety System Certification
GMPs	Good Manufacturing Practices
HACCP	Hazard Analysis and Critical Control Points
IPM	Integrated Pest Management
ISO	International Organization for Standardization
ISO TS	International Organization for Standardization Technical specification
KORE	Coca-Cola Operating requirements
MA	Moving average
NA	Not Applicable
PRP	Prerequisite Program
RQ	Requirement
SARL	Société à Responsabilité Limitée
SPA	Société par actions
STL	Seasonal trend loess
STL	Seasonal-Trend decomposition
VBA	Visual Basic for Applications

General introduction

Food is a fundamental necessity, placing the food industry at the heart of every nation's economic infrastructure. This industry faces numerous challenges, particularly in maintaining food safety and quality standards. In Algeria, the continuous population growth increases the growing demand in food production, amplifying various associated risks. These latter predominantly pertain to food quality which is the most crucial aspect of consumer goods.

Within this context, effective pest control emerges as a significant challenge in the industry. Pests severely affect food safety, quality, and the operational productivity by introducing various pathogens and causing structural damage. Campbell et al. in 2020 found that the presence of pests in food facilities could cause up to a 30% increase in food spoilage rates, significantly affecting the bottom line for food producers [1]. As traditional pest control methods prove inadequate for modern production demands, adopting advanced pest management strategies becomes imperative.

This study, conducted at the Equatorial Coca-Cola Bottling Company Rouiba (ECCBC Rouiba), aims to assess the company's adherence to Coca Cola's pest control standards and to identify the major challenges it faces in maintaining effective pest management. The research is driven by three questions. The first one is *(i)* what are the challenges faced in maintaining effective pest control within facilities?, the second one is *(ii)* how can analyzing pest related data optimize the design of pest control program?, and the last one is, *(iii)* how can traditional pest management practices be improved to effectively respond to pest-related risks?

To address these questions, a variety of methods and programming tools were employed. The evaluation of compliance and identification of challenges were based on Coca Cola's standard. The improvement phase involved a detailed pest analysis derived from these standards, coupled with the organization and analysis of current data monitoring. Predictive modeling was conducted in order to enhance the prevention aspect.

Additionally, a new risk evaluation algorithm was developed to determine the action threshold using a standard approach. This led to the creation of a comprehensive interface, which consolidates all data pertaining to our Integrated Pest Management (IPM) system, ensuring a streamlined and effective pest control strategy.

The plan of this thesis starts with the first chapter, which provides an overview of company ECCBC. It, also, discusses the historical evolution of pest control methods and the principles of Good Manufacturing Practices (GMP) and Integrated Pest Management (IPM). Following that, chapter two details the evaluation of ECCBC's pest control measures against the KORE PRP-RQ-018 requirements. It includes the creation of a compliance checklist, the assessment criteria, and the discussion of the results. It identifies strengths and areas for improvement and formulates an action plan to address the compliance gaps. Then, chapter three conducts a comprehensive pest analysis to identify the types of pests present within the facility and the factors influencing their presence. It discusses the impact of local environmental characteristics on pest populations and describes the data management and predictive models developed to forecast pest activity. Finally, chapter four describes the design of a dynamic risk evaluation algorithm and the development of the IPM 1.0 interface. It explains how the interface integrates all pest control data, supports dynamic risk evaluation, and streamlines reporting. In addition, it discusses the implementation and effectiveness of the IPM 1.0 system in enhancing pest management at ECCBC.

Chapter I

Equatorial Coca-Cola Bottling Company and Pest control Overview

I.1 Introduction

This chapter is divided into two parts to provide an overview of pest control and Equatorial Coca-Cola Bottling Company.

In the first part, I present an overview of the Equatorial Coca-Cola Bottling Company (ECCBC) and its operations. This covers the company's history, its commitment to quality, and highlights its organizational structure, production facilities, and the standards it complies with.

In the second part, I provide an overview of pest control through a bibliographic synthesis. It defines pest control and explains its relationship with Good Manufacturing Practices. Finally, it outlines the key elements of Integrated Pest Management.

I.2 Equatorial Coca-Cola Bottling Company overview

FRUITAL Coca-Cola was established in 1993 as a soft drink manufacturer and quickly became the market leader.

On March 15, 2006, the Spanish group ECCBC (Equatorial Coca-Cola Bottling Company) becomes a shareholder of the company Fruital SPA and acquires 92% of its shares to become one of the bottlers and distributors of Coca-Cola in Algeria. It imports manufactured concentrates by the Cola Company and ensures marketing and distribution through its contemporary distribution methods to fulfill the needs of all clients and consumers.

Fruital operates in 13 wilaya including Algiers, Blida, Boumerdes, Tizi-Ouzou, Tipaza, Médéa, Ain Defla, Bouira, BBA, Laghouat, Djelfa, Ghardaïa, Tamanrasset.

In July 2022, ECCBC merged its non-alcoholic beverage business with Castel Group to form a consolidated market leader that operates as a single entity in the country, with ECCBC as the dominant partner. ECCBC Algeria operates three production facilities: two in the region of Skikda and Oran, and one in Algiers. Between the three locations, there are about 2,000 workers total [1].

I.2.1 Rouiba plant

Representing one of the most important factories in the region, the facility focuses its investments on the manufacturing and management of soft drinks. It prioritizes innovation and flexibility, whether it is about integrating new technology or offering a broad variety of bottling options, including [2]:

- ✓ PET bottles: 50 cl, 100 cl, 1.5l and 2l,
- ✓ Glass: 25 cl, 30 cl and 1l,
- ✓ Cans: 25 cl, 33 cl.

I.2.1.1 Localisation

FRUITAL is located in the industrial area of Rouïba, RN n°5 16013 Rouïba, Algiers, Algeria.

It is delimited by:

- North: National Road 5.
- West: Habitat.
- South: Railway line.
- Southwest: Rouiba Hospital.
- East: SARL TANGO.

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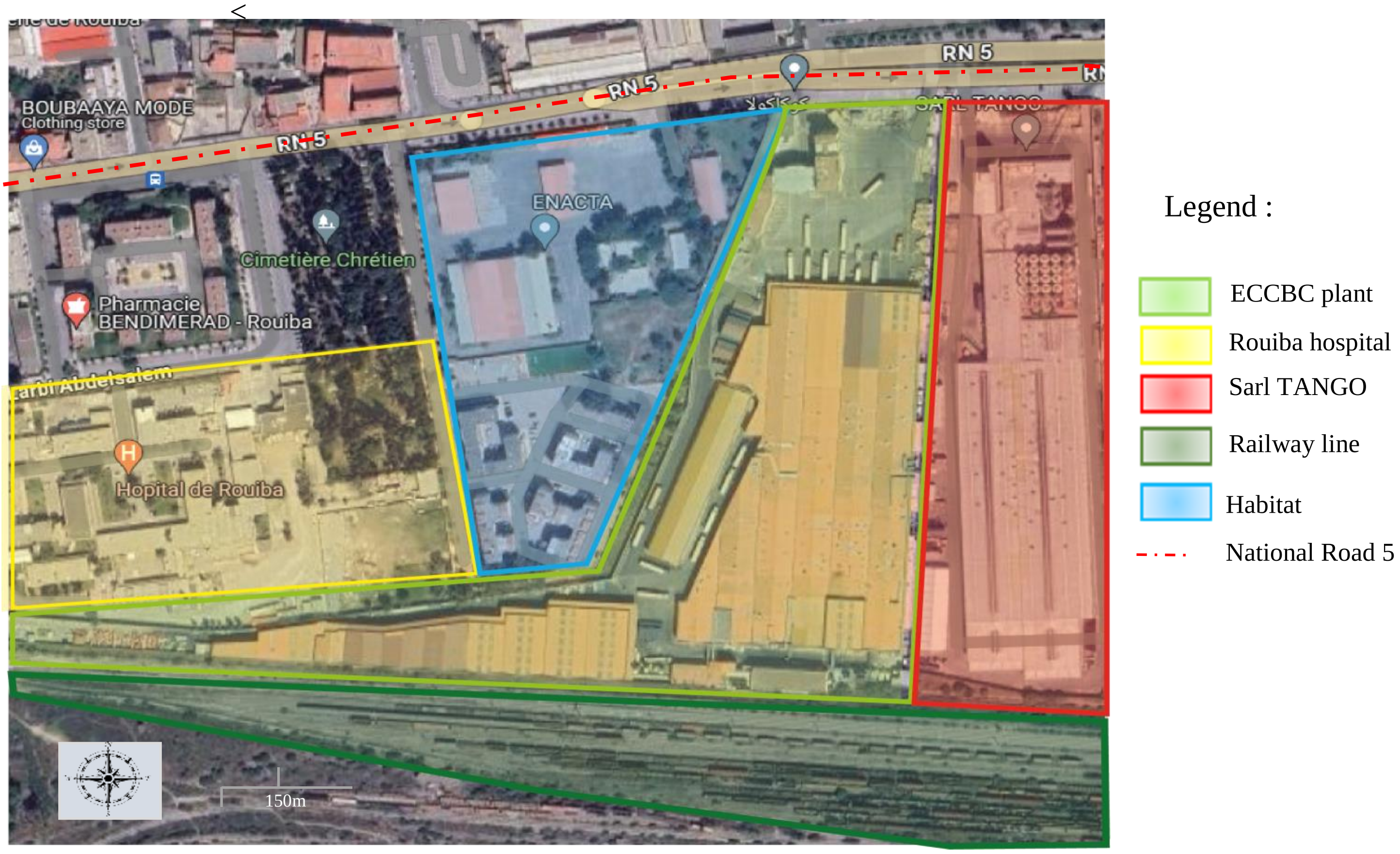


Figure I-1 Location and Borders of ECCBC [48]

I.2.2 Fruital Organizational Chart

The organizational chart of Fruital (figure I-2) illustrates the company's hierarchical structure, highlighting the various departments and their interrelations.

The quality department is an important part of the operations department. Its main role is implementing and maintaining strict quality control measures. One of its functionalities is pest control. The quality department ensures that ECCBC's products meet the highest safety and quality standards, thereby protecting consumer health and maintaining the company's reputation.

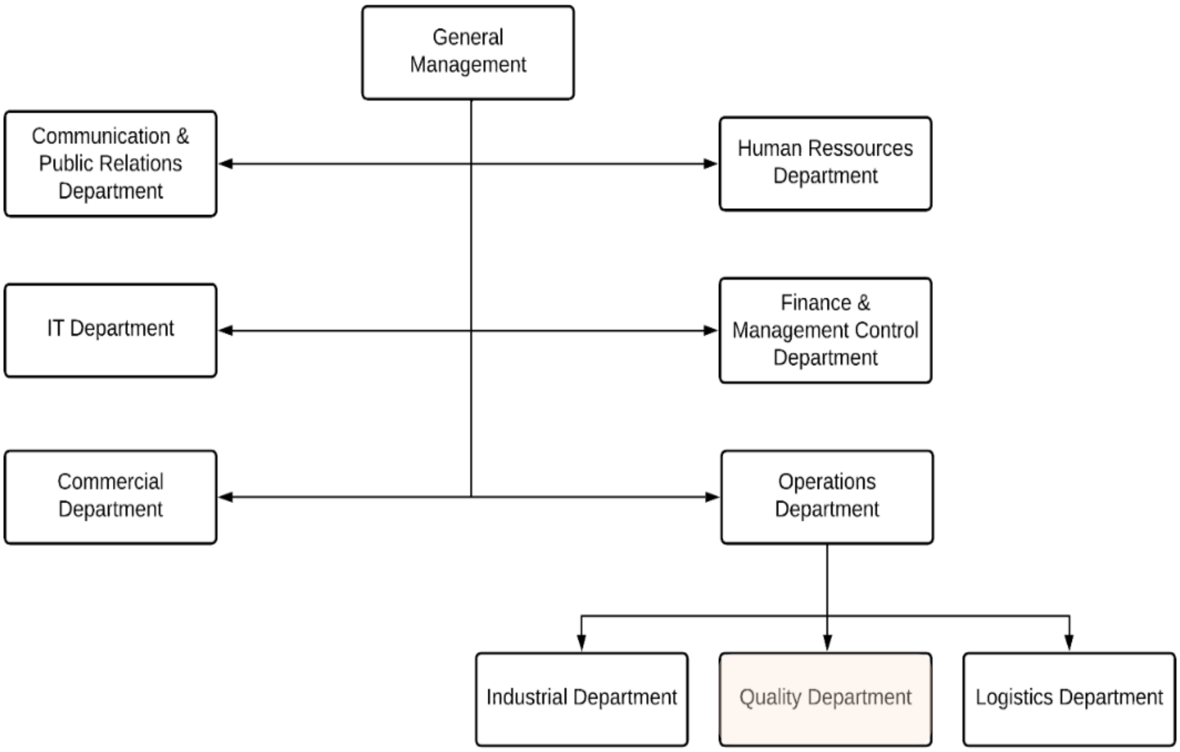


Figure I-2 ECCBCA Organizational Flowchart

I.2.3 Beverage Process

To highlight the commitment to quality and efficiency, I will examine the detailed steps involved in creating and delivering the products from factory to consumer, at every stage.

I.2.3.1 Beverage production process

This process includes all manufacturing processes, from receipt of the production schedule to storage of final items. It encompasses handling sugar and CO2 as well as bottling and syrup processing.

The goal is to assure timely and cost-effective manufacturing of a compliant product while following to standards and laws, protecting the environment, and assuring the onsite staff safety.

It is important to note that the raw materials are:

- **Water:** Major component (92%), rigorously monitored for quality.
- **Sugar:** Comprised of sucrose (from sugar beets and sugarcane) and dextrose (from corn).
- **Carbon Dioxide (CO2):** Used for preservation and to provide a refreshing taste.
- **Concentrate:** A complex mixture of flavors, acidifiers, and colorants produced by Coca Cola.

It is important to say that these components are stocked in different places in the plant.

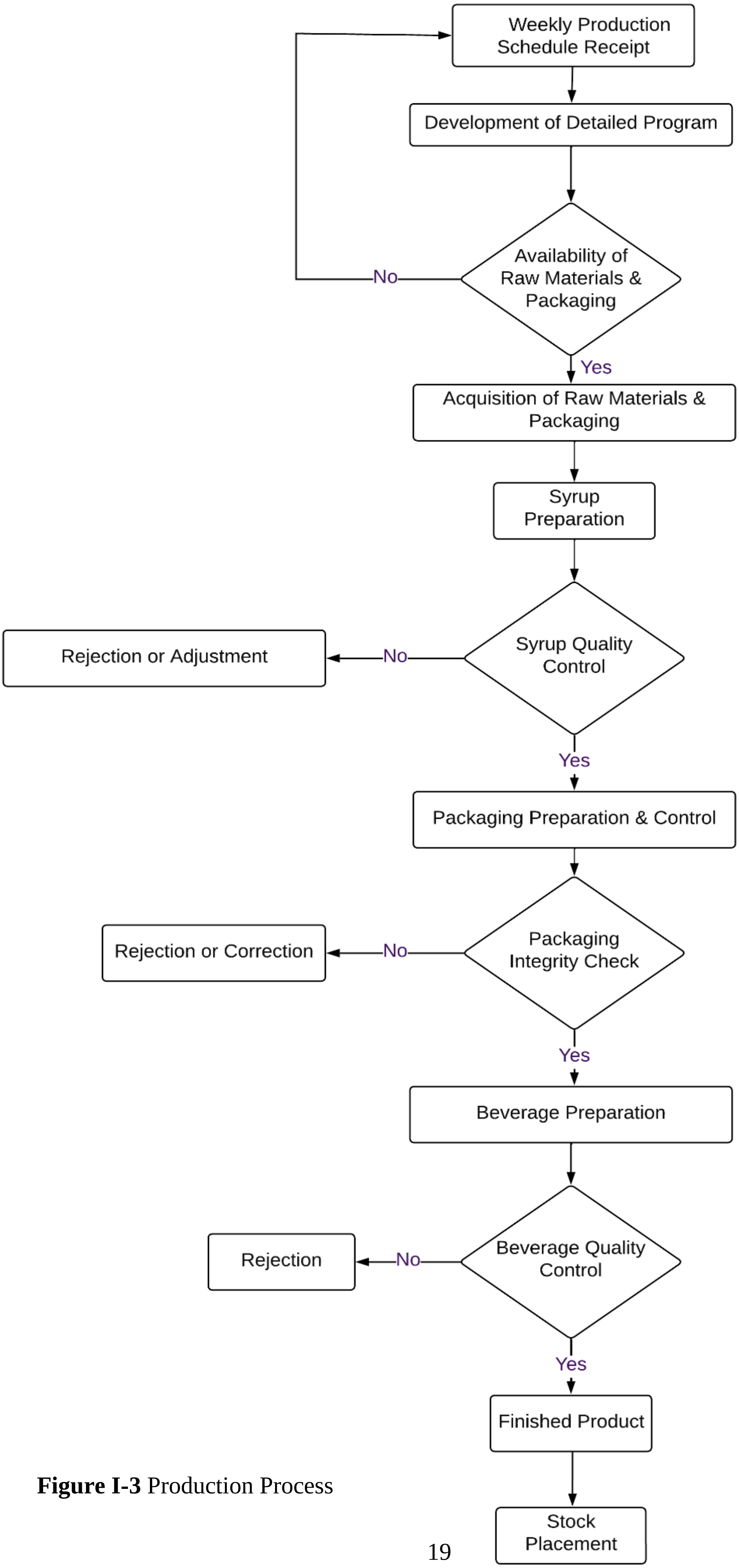


Figure I-3 Production Process

I.2.3.2 Distribution Process

The distribution process takes place following the production phase. It includes all activities related to managing finished product inventories. Along with planning client deliveries, it also addresses optimizing product loading for direct and indirect consumers.

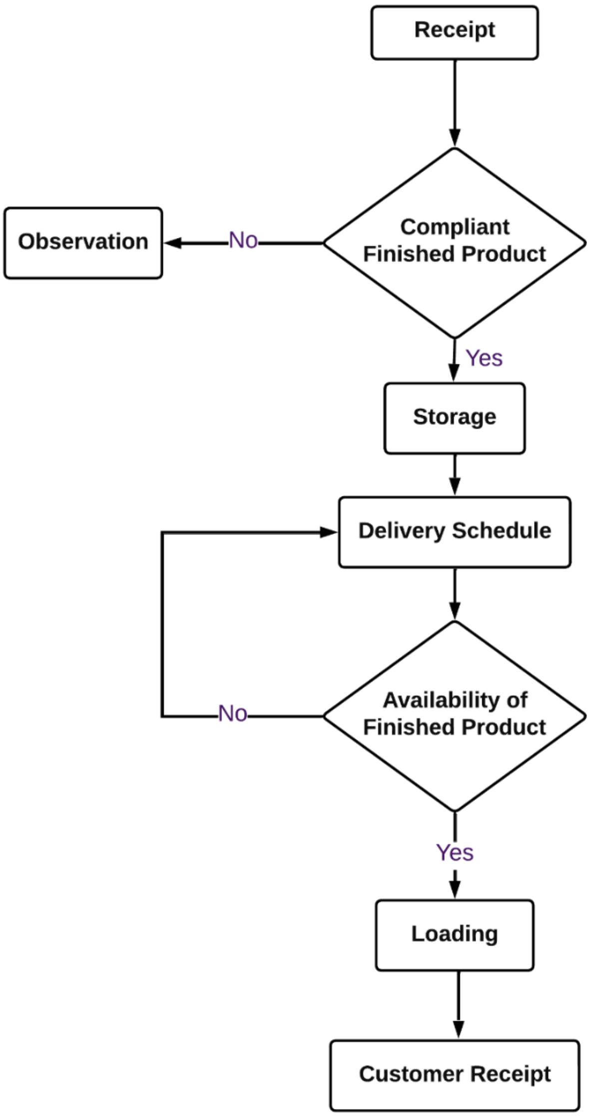


Figure I-4 Distribution process steps

I.2.4 Certifications and standards at ECCBC Algeria

The Equatorial Coca-Cola Bottling Company is dedicated to maintaining the highest quality and safety standards in its operations. This is reflected in their compliance with several prestigious certifications and standards, including:

- ISO 9000 and ISO 9001 to ensure consistent quality management system;
- KORE (The Coca-Cola Operating Requirements), which are specific to Coca Cola's global standards;
- ISO 14001 for environmental management;
- ISO 45001 for occupational health and safety;

- FSSC 22000 and ISO 22000 for food safety management, and ISO TS 22002-1.

I.3 Overview on pest control

This section examines pest control practices, highlighting their essential role in maintaining food safety and quality in the food industry. It will explore the historical evolution of pest control methods, displaying key milestones and advancements that have influenced current practices. Additionally, the section will discuss the significance of pest control within the framework of Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP). It will outline how integrated pest management (IPM) strategies are implemented to mitigate risks and ensure regulatory compliance.

I.3.1 Pest control's bibliographic synthesis

Pest management has been practiced for millennia and has continually evolved with advancements in science and technology. Traditionally, pests were controlled by physical barriers, crop rotation, and the employment of natural predators in early agricultural communities. For example, as early as 2500 BCE, the Sumerians controlled insects with sulfur compounds, and the Egyptians and Chinese protected their crops and food storage by using traps and botanical insecticides [3]. European farmers created techniques that are more methodical during the Middle Ages, such as introducing predator animals and using insecticides derived from plants [4]. Mechanical traps and chemical fumigants, such arsenic compounds and tobacco infusions became popular in the 17th century.

Pest control became a formalized part of the food industry in the early 20th century with the advent of modern food safety regulations. As food production scaled up during the Industrial Revolution, the need to prevent contamination and ensure safe food storage became more pressing. The Food and Drug Administration (FDA), established in 1906, played a crucial role in implementing food safety standards, including pest control measures [5].

The 20th century marked a significant turning point with the discovery of synthetic pesticides like DDT in the 1940s. These chemicals provided highly effective pest control solutions but also raised environmental and health concerns due to their persistence and toxicity. This led to the development of Integrated Pest Management (IPM) in the 1960s and 1970s. IPM emphasized a combination of multiple control methods and sustainable practices, aiming to minimize the use of harmful chemicals [6].

Technology, regulatory scrutiny, and sustainable practices have all contributed to considerable developments in recent decades. The adoption of IPM combines multiple strategies to manage pest populations effectively. Businesses can anticipate insect outbreaks and take early steps by analyzing historical data and environmental conditions. Analyzing historical data and environmental factors enables companies to predict pest outbreaks and implement proactive measures, optimizing resource allocation and reducing pest-related issues [7].

These developments protect consumers as well as the environment by enforcing strict safety and hygienic standards in the food business. Sustainable practices, advanced technologies, and stringent regulations contribute to effective pest management strategies, making the industry resilient to pest-related challenges.

I.3.2 Good Manufacturing Practices definition

Good Manufacturing Practices (GMPs) in the food industry are critical guidelines designed to ensure that food products are consistently produced and controlled according to quality standards, minimizing the risks inherent in production that cannot be eliminated by testing alone [8]. These practices encompass a wide range of operational areas, including facility design to prevent contamination, rigorous control of air, water, and energy supplies, and strict cleaning and sanitizing protocols [9]. GMPs also mandate comprehensive pest control and enforce sanitation and hygiene practices to protect against both direct and indirect contamination [10]. By requiring that, all personnel—from production workers to managers and visitors—adhere to these practices, GMPs safeguard consumer health and enhance product integrity, maintaining high standards across the entire food production and distribution process [11].

I.3.3 The Importance of pest control in food safety management systems

In the food industry, Prerequisite Programs (PRPs) are key to establish and maintain a hygienic environment. These programs set the basic environmental and operational conditions for safe production of food. One specific type of PRP is Good Manufacturing Practices (GMP), which ensure the upkeep of fundamental operational conditions within the food production environment. GMPs cover a range of aspects, including pest control, personal hygiene, sanitation, and equipment maintenance [12].

Pest control is a critical element of GMP. This later is indispensable in supporting the effective implementation of HACCP. They ensure that the necessary conditions for food safety are in place and consistently maintained.

The integration of pest control within GMP as part of PRPs is crucial for creating a secure environment for food production. This integration not only ensures comprehensive food safety but also facilitates the adoption of advanced food safety management system (HACCP), thereby providing a holistic approach to food safety throughout the food chain.

I.3.4 Integrated Pest Management (IPM)

The late RJ Prokopy defined integrated pest management (IPM), in 2003, as *"...a decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pests (insects, pathogens, weeds, vertebrates) in an ecologically and economically sound manner."* [13]

It is a sustainable approach for managing pest population through the combination of multiple control methods. The main goal is to reduce the risks to human health and environment. Its strategies involve using biological, cultural, physical, and chemical tools to maintain pest populations at acceptable levels.

For the IPM practitioner, this implies simultaneous management of multiple pests; regular monitoring of pests, and their natural enemies and antagonists as well; use of economic or treatment thresholds when applying pesticides; integrated use of multiple, suppressive tactics [14].

This integrated approach is designed to be effective, economically feasible, and environmentally responsible, in order to ensure the safety and quality of food products throughout the production and processing stages.

I.3.4.1 The importance of IPM

The IPM has many benefits. This includes:

(i) Protecting consumers from foodborne diseases by preventing pests from contaminating food products with pathogens;

(ii) Making the pest control management more cost-effective than conventional pest control methods by concentrating on long-term prevention.

(iii) Improving health and safety by minimizing the exposure of workers and consumers to harmful chemicals, reducing pesticide residues in food products, and enhancing food safety and consumer confidence [15].

I.3.4.2 Theoretical foundations of IPM

Integrated Pest Management (IPM) is a holistic, environmentally friendly approach to pest control that emphasizes the use of a variety of common-sense practices. It is not merely a single method of pest control but rather a comprehensive strategy that involves continuous evaluations, decisions, and controls. At the core of IPM is a deep understanding of the life cycles of pests and their interactions with the environment. This knowledge, combined with a range of pest control techniques, is employed to minimize pest damage in the most cost-effective manner while ensuring minimal risk to humans, property, and the environment.

In implementing IPM, a four-tiered approach is adopted to proactively manage potential pest infestations. This structured method ensures that all aspects of pest management are considered and integrated into a cohesive strategy [14].

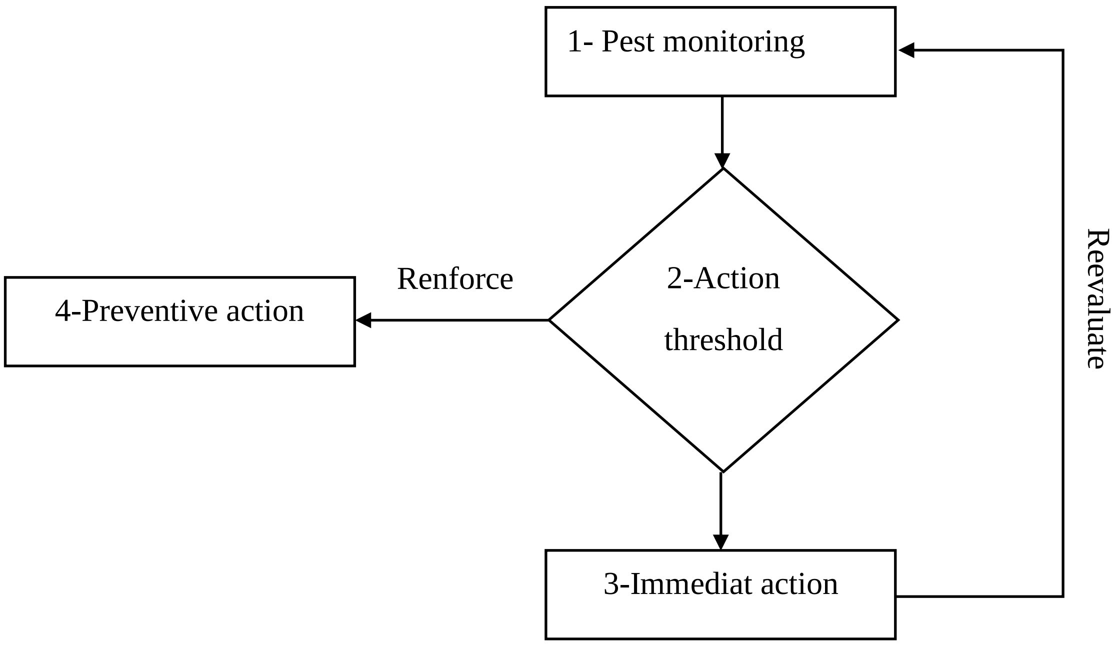


Figure I-5 Simplified Integrated Pest Management (IPM) flowchart

To visualize this process, the figure I-5 is developed outlining the steps of the IPM approach:

Step 1: it involves the monitoring of pest populations in the food production environment. It can include the use of traps, visual inspections, and other detection methods to identify the presence and density of pests.

Step 2: Once pests are monitored, we can calculate the level threshold. This threshold represents limit at which control measures must be taken to avoid food safety risks.

Step 3: If the threshold level exceeds the action threshold limit, immediate control measures are taken to reduce pest populations to acceptable levels. These measures can include physical, mechanical, or most likely chemical methods, depending on the assessment of the situation and potential impacts.

Step 4: Preventive actions are proactive measures that are implemented to mitigate the risk at the source.

After Immediate Action, the process loops back to Pest Monitoring to assess the effectiveness of the actions taken and to continue the cycle of monitoring and prevention. The cyclic nature of the diagram emphasizes the ongoing and adaptive process of IPM, ensuring continuous improvement and response to changing conditions

I.4 Conclusion

In conclusion, this chapter has provided a detailed overview of the Equatorial Coca-Cola Bottling Company's operations and the critical role of pest control in maintaining food safety standards. I detailed the company's background, its wide-ranging production and distribution network throughout Algeria, and its strict adherence to quality requirements.

I also explored the evolution of pest control practices through a bibliographic synthesis. Emphasizing the importance of pest control within Good Manufacturing Practices (GMP), I outlined how IPM integrates various control methods to ensure food safety and compliance with regulatory standards. Finally, I delved into the theoretical foundations of IPM, which involves continuous monitoring, threshold-based decision-making, immediate actions, and preventive measures.

Chapter II

Pest control Evaluation and action planning

II.1 Introduction

This chapter presents the evaluation of the pest control measures currently implemented at ECCBC in relation to the KORE PRP-RQ-018 requirements. The goal of this evaluation is to ensure that ECCBC's pest management practices align with Good Manufacturing Practices (GMP). I will outline the scope of the PRP-RQ-018 standard, and explore its key components. Then I will assess

ECCBC's compliance though a compliance checklist. Finally, I will use the findings from this evaluation to develop an action plan to address the identified gaps.

II.2 Overview of KORE Requirements in Pest Control

KORE is an internal Coca-Cola standard. PRP-RQ-018 is one of its components that defines the essential pest control requirements. It is designed specifically for facilities associated with The Coca-Cola Company, to protect the quality of the products and enhance the working environment for staff by preventing pest-related issues.

II.2.1 Scope of application of the PRP-RQ-018 standard

This standard is applicable to all facilities that manufacture and/or distribute for or on behalf of the Coca-Cola Company. It defines the required pest management procedures and protocols that must be followed to maintain compliance with Good Manufacturing Practices (GMP) and assure food safety across all operational sites.

II.2.2 Key Components of PRP-RQ-018 Pest Control

The PRP-RQ-018 Pest Control document establishes a structured framework to ensure effective pest management within facilities adhering to Good Manufacturing Practices (Figure II-1).

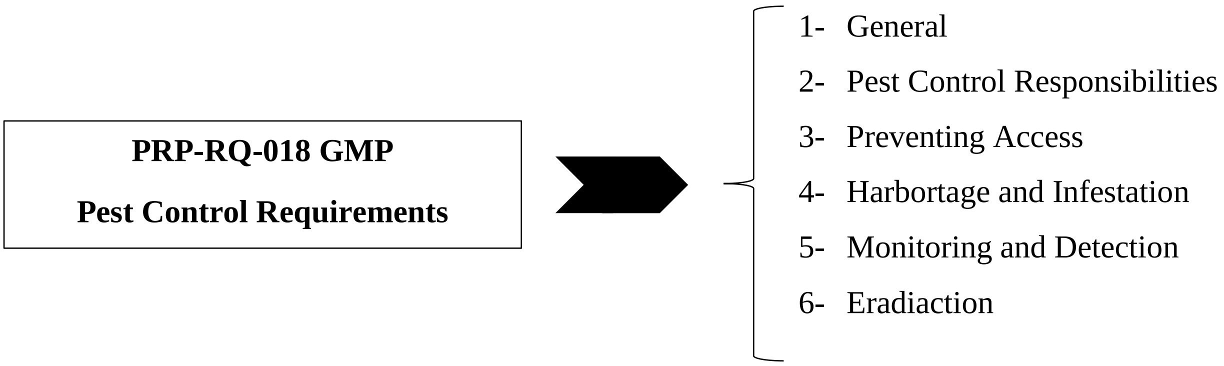


Figure II-1 Key Components of PRP-RQ-018 Pest Control

This figure encapsulates the essential elements of the requirements for maintaining an effective pest control program in food manufacturing and distribution facilities, as outlined in the PRP-RQ-018 GMP Pest Control standard (Appendix 1).

II.3 Evaluation of ECCBC compliance to PRP-RQ-018

In this section, I will evaluate ECCBC's pest control measures against the PRP-RQ-018 requirements. This evaluation involves developing a detailed checklist, conducting thorough inspections and interviews with the staff, in order to assess the compliance and finally identify strengths and areas for improvement. Following that, I will be transforming them into an action plan.

II.3.1 Creation of the compliance checklist

I began by thoroughly analyzing the PRP-RQ-018 document. Each requirement was broken down into measurable elements that could be clearly assessed. Then I translated each of these points into specific, actionable checklist items. Following that, I determined the necessary evidence to evaluate each item objectively. Finally, I organized the items/ questions into several key categories that reflect the major sections of the PRP-RQ-018 document (**Figure II-1**)

II.3.1.1 General practices requirements

The first category is general practices. This involves assessing documentation, identifying target pests, and evaluating the overall comprehensiveness of the pest control program. The table II-1 represents its requirements, in form of questions.

Table II-1 General Practices requirements

ID	Requirement
General	How can we integrate an effective pest management system to enhance overall food safety and quality within our production facilities?
	How is your pest control program documented to identify target pests?
	Does the analysis effectively cover the common types of pests and animals, considering their presence in various environments?
	To what extent does the design of the pest control program incorporate considerations of the external surrounding environment?
	How effectively does the design of the pest control program assess local surrounding businesses to identify potential pest attractions?
	To what extent does the developed pest control program address the effectiveness of pest management measures relative to the proximity to the point of manufacturing?
	How effectively does the implemented pest control plan ensure that all chemicals and traps comply with local legislation and do not pose a risk to employees, products, or the environment?

II.3.1.2 Pest control responsibilities requirements

The second category is pest control responsibilities. This involves evaluating the training, qualifications, and effectiveness of personnel, including third-party contractors. The table II-2 represents its requirements, in form of questions.

Table II-2 Pest control responsibilities requirements

ID	Requirement

Pest Control Responsibilities	How effectively do operations contracting pest control services, to a third party ensure that the contractor, possesses the necessary capabilities, training, and understanding to conduct pest control activities in food manufacturing facilities?
	How regularly are audits conducted on the pest control program to verify its effectiveness?

II.3.1.3 Preventing access

The third category is preventing access. This involves checking for structural integrity and preventive measures to stop pests from entering the facility. The table II-3 represents its requirements, in form of questions.

Table II-3 Preventing access requirements

ID	Requirement
Preventing access	How consistently are buildings maintained in good repair, are potential pest access points such as holes, and drains adequately sealed?
	How effectively are external doors, windows, and ventilation openings designed to minimize the potential for entry of pests?
	Are all doorways appropriately sealed at ground level to prevent rodent entry?
	How are frequently used doorways managed to prevent entry of birds and other pests?
	Are suitable prevention devices used in areas where the potential for bird activity exists?
	Are air curtains utilized on doors to processing areas as a deterrent to the entry of flying insects?

II.3.1.4 Harborage and infestations requirements

The fourth category is harborage and infestations. This involves Ensuring that conditions do not allow pests to live or multiply within the facility. The table II-4 represents its requirements, in form of questions.

Table II-4 Harborage and infestations requirements

ID	Requirement
Harborage and infestations	How are your storage practices designed to minimize the availability of food and water for pests?

	Describe the processes included in your incoming material receiving program to inspect materials and shipping devices for pests.
	How do you inspect incoming ingredients and package integrity for signs of pest infestation?
	What procedures are in place to immediately isolate materials found to be contaminated with pests?
	How do you manage materials found to be infested with pests, especially in terms of using or disposing of these materials?
	What process is in place for inspecting pallets for pest activity before use within the facility?
	Can you describe the policies regarding the use of fumigation and insecticide sprays to ensure they are not applied directly on ingredients, packaging, or final products?
	How do you maintain the facility grounds to prevent areas of infestation?
	Could you provide documentation that illustrates how your facility's waste storage, including the use of trash compactors and refuse containers, is managed to prevent pest attraction and harborage, and how these are maintained in a sanitary manner?
	How your waste storage practices are designed to prevent pest attraction and harborage, including details on storage methods, frequency of waste removal, and staff training on these practices?
	What measures are in place to avoid the build-up of old machine/equipment parts or building materials that could harbor pests?
	How are areas within the facility where infestation may occur identified and included in routine inspection and pest control activities?

II.3.1.5 Monitoring and detection requirement

The fourth category is monitoring and detection. This involves reviewing the placement and maintenance of pest monitoring devices. The table II-5 represents its requirements, in form of questions.

Table II-5 Monitoring and detection requirements

ID	Requirement
Monitoring and detection	Can you provide detailed evidence of your pest-monitoring program, specifically regarding the placement of detectors and traps throughout the facility?

II.3.1.6 Eradication requirements

The last category is eradication. This involves Evaluating the responsiveness and effectiveness of pest eradication measures. The table II-6 represents its requirements, in form of questions.

Table II-6 Eradication requirements

ID	Requirement
Eradication	What immediate eradication measures are implemented after evidence of pest infestation is reported, and how do these measures comply with local regulations?
	How do you ensure clean-up activities from infestations, such as bird nests or droppings, prevent the spread of disease or contamination?
	Can you demonstrate that pesticide use and application are restricted to trained operatives and controlled to avoid product safety hazards?
	How are records of pesticide use maintained, detailing type, quantity, concentrations used, application details, and target pest?
	Are exterior monitoring devices or bait stations for rats and mice tamper-resistant, anchored, and properly labeled?
	What internal control programs are in place for pest management, and do they comply with legal and safety standards?
	How are electric flying insectocutors placed to avoid attracting insects inside the plant and prevent contamination?

After establishing all the requirements and organizing them into a table, I assigned at least one piece of evidence to each requirement. This approach aims to streamline the evaluation process, making it faster and more efficient by directly linking requirements with their corresponding evidences. The next step involves the assignment of compliance percentages based on the evidence observed during the assessment.

II.3.2 Compliance assessment criteria

Each checklist item is evaluated against the evidence presented for each requirement and assigned a compliance percentage from a scale of 0%, 20%, 40%, 60%, 80%, to 100%.

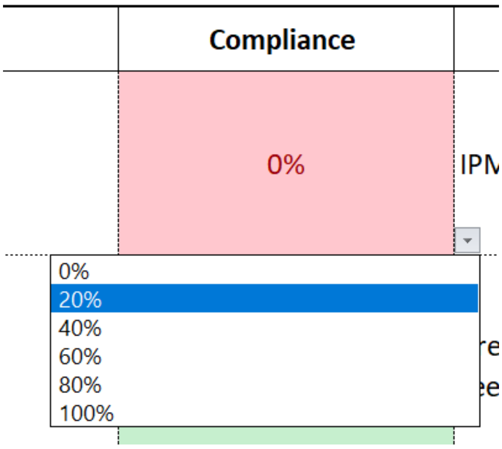


Figure II-2: Demonstration of Assessment Criteria sample

These percentages reflect :

- **0%:** No evidence of compliance;
- **20%**: Minimal evidence of compliance;
- **40%**: Some parts of the requirement are met but many aspects are lacking;
- **60%**: More than half of the requirement is met with some significant deficiencies;
- **80%**: Most of the requirement is met with only minor deficiencies;
- **100%**: Full compliance with the requirement.

II.3.3 Implementation and Review

I have conducted a comprehensive compliance review using firstly **(i)** the checklist made previously and validated by the technical staff, alongside with **(ii)** physical inspections, which lasted about three weeks, **(iii)** personnel interviews, and **(iv)** review of relevant documentation. The gathered evidence was then matched against the checklist criteria to assign a compliance percentage to each item. The results were documented and presented in Appendix 2.

II.3.4 Results discussion

The result of the previous work demonstrates the evaluation of the current pest control practices against the PRP-RQ-018 requirements. To effectively visualize these compliance levels, I utilized a radar chart. This type of chart is particularly suited for our needs because it allows us to display multiple compliance categories on a single graph.

The radar chart (figure II-8) visualizes the current compliance levels in a triangular representation, effectively illustrating areas of optimal, partial, and insufficient compliance. The peak point of the triangle, reaching just around level 4, indicates that while some areas meet the moderate compliance threshold, there is a significant gap in reaching the high compliance mark set at 20. This graphical representation clearly underscores the need for targeted improvements in specific areas to elevate our overall compliance.

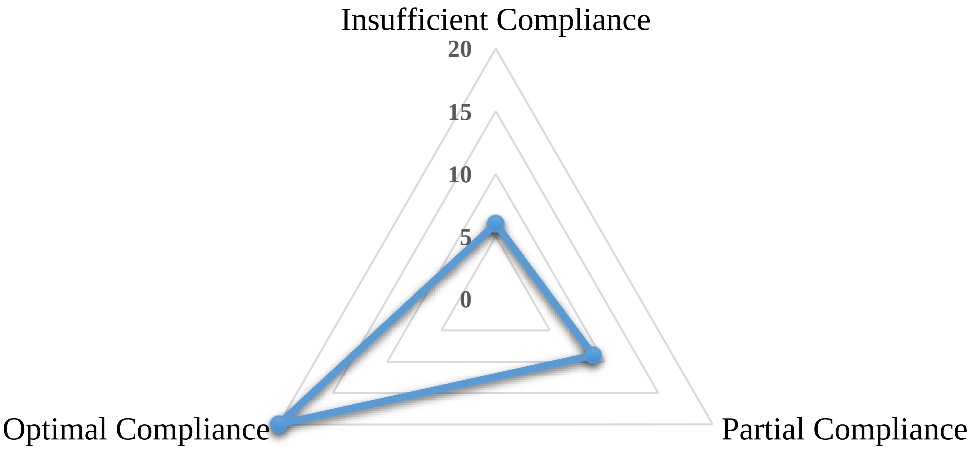


Figure II-3 Radar chart of the compliance to PRP-RQ-018 requirements

The recent compliance review has brought us to 70% compliance level, highlighting the strong commitment in several key areas. However, it also shows on vital areas for improvement specifically in preventing access, managing harborage and infestations, and enhancing our monitoring and detection practices.

To address these gaps, I developed an action plan prioritizing several key measures.

II.4 Action Plan to improve the compliance

The table II-7 serve as a structured action plan to address identified non-compliances. Each action item in the table is formulated to target specific areas of improvement, from enhancing Integrated Pest Management (IPM) practices to creating databases/logs of pesticide use.

Table II-7 the action plan

N°	Action Item	Priority
1	Implement an IPM system	1
2	Develop formal pest control procedures	1
3	Review and update current pest control methods	2
4	Perform comprehensive pest analysis	1
5	Generate environmental impact reports	3
6	Pest control measures optimized based on the distance from the manufacturing point	2
7	Install Air Curtains in essential entrances and near white zone	1
8	Assess bird activity around facility	2
9	Consider the effectiveness of the procedures (storage practices)	2
10	Procedures for pest elimination from infested materials	1
11	Records of regular clean-ups Disposal Procedures Documentation: Providing procedures for the proper disposal of old machine/equipment parts and building materials	2
12	Pest-Monitoring Program including: Processes for the placement of detectors and traps	1
13	Position at 15 to 30-meter (50 to 100-foot) intervals along exterior perimeter walls and elsewhere if appropriate	2
14	Effectiveness assessments od the pest control program	2
15	Logs or databases of pesticide use	1

Note: The charter ranks priorities as 'High,' 'Medium,' and 'Low,' designated by the numbers 1, 2, and 3 respectively. The items classified as **'High'** priority are addressed first due to their critical nature. **'Medium'** priority items follow, which are important but do not have the immediate impacts of high-priority issues, while **'Low'** priority items are attended to last, as they are the least critical.

II.5 Conclusion

In this chapter, I evaluated the pest control measures at Equatorial Coca-Cola Bottling Company (ECCBC) against the KORE PRP-RQ-018 requirements to ensure compliance with Good Manufacturing Practices (GMP). This assessment involved creating a detailed compliance checklist, conducting inspections, and analyzing the effectiveness of current pest control practices.

The evaluation revealed a compliance level of 70%, indicating strong adherence in several areas but highlighting significant gaps.

To address these gaps, I developed an action plan prioritizing the conducting a pest performing comprehensive pest analysis, implementation of an Integrated Pest Management (IPM) system and updating pest control procedures between many others.

In the next chapter, I will focus on enhancing compliance with the KORE requirements for pest control. This will involve implementing the actions outlined in the action plan starting with pest analysis.

Chapter III

Pest analysis and predictive model development

III.1 Introduction

This chapter focuses on the improvement of ECCBC's current pest control practices following the action plan. First, I conduct a comprehensive analysis to identify the types of pests present within the facility and the factors influencing their presence. The analysis also includes the impact of local environmental characteristics on pest populations. Following the findings, I worked on the data management and the implementation of advanced predictive models to forecast pest activity. The goal of this proactive and data-driven approach is to enhance the effectiveness and sustainability of ECCBC's pest control practices.

III.2 Pest Analysis

A comprehensive pest analysis is essential to understand the types of pests present within the facility and to develop targeted control measures. This involves identifying the different pest species, understanding their activity signs, relationship with their habitat [16], and assessing the effectiveness of the implemented strategies [17].

III.2.1 Identified Pest Types

The range of pests found in food processing plants will vary according to climate, geography and food ingredients processed. It is important to determine if the pest lives and develop inside or outside the facility. Usually, pests live and develop outside are the Intrinsic species while those that live and develop in products are extrinsic pests. An information that is worth mentioning is that the pests that live and develop inside the facility can be either extrinsic or intrinsic [7].

Therefore, I classified the pests that can be found in the facility into three categories:

III.2.1.1 Intrinsic pests

Within ECCBC's facilities, we have been able to identify several species that exist, grow, or engage in major interactions. These species actively interact with the internal ecology, which presents varying degrees of management difficulties. The identified pests include ant, flies, spiders, cockroaches, mosquitos, rodents (rats and mice), and stored product insects [18].

III.2.1.2 Extrinsic animals

At ECCBC facilities, we have identified pests that are typically found outside but can occasionally be found inside. They rarely step in, but if they do, they are usually in connection with an event occurring outdoors. Here is a basic overview of these pests, cats, lizards, snakes and frogs [18]

III.2.1.3 Special consideration

In the ECCBC facilities, special consideration is given to managing pests classified under a distinct category due to their unique nature and the specific challenges they pose. This category encompasses honey bees and paper wasps [18]

III.2.2 Relationship between pests and their habitat

Pest-habitat interactions are complex, influencing pests ability to thrive, reproduce, and become problematic in a variety of contexts, especially in the food sector. A variety of factors influences this relation such as food availability, shelter, temperature, humidity. That can either attract or repel different pest species. The table III-1 summarizes the attracting factors.

Table III-1 the influence of some environmental factor on pests

Factor / Pest	Food Availability	Shelter and Nesting Sites	Temperature	Humidity and Moisture	Note
Ants	✓	✓	✓	✓	Around **24.1°C**, High humidity
Spiders	✓	✓	✗	✓	Venomous and Hazardous Species
Mosquitos	✗	✗	✓	✓	Température : **20°C et 30°C**
Stored Product Insects	✓	✓	✗	✗	Activity often increases in dark
Flies	✓	✓	✓	✗	Around **30 °C**
Birds	✗	✓	✗	✗	
Cockroaches	✓	✓	✓	✓	Prefer dark, moist environments (**60%** et **80%**), **25°C** à **33°C**
Rodents	✓	✓	✓	✗	Nocturnal; prefer darker areas, Température : **20°C - 24°C**
Cats	✗	✓	✗	✗	
Snakes	✗		✓	✗	
Lizards	✗	✓	✗	✗	
Frogs	✗		✓	✓	
Honey Bees	✓	✗	✗	✗	Attracted to sugary substances and water sources for hydration and food
Paper Wasps	✓	✗	✓	✗	Important for the environment, but their presence inside facilities can be hazardous.

Note: Even though the comprehensive analysis presented in the pest factor chart includes all existing pests, my study will specifically focus on rodents, flies, and mosquitoes. These pests have been selected due to their significant impact on food safety and operational hygiene within the facilities, as well as the existing monitoring efforts already in place for them within the company. This focus allows us to adopt a quantitative approach in studying these pests, providing detailed insights and actionable data. Additionally, this approach leaves room for future development, enabling the project to expand and encompass other pests as needed.

III.2.3 Influence of Local Environmental Characteristics

The impact of local environmental factors on pest populations and behavior is an important aspect of pest management. Local environmental factors such as climate, topography, vegetation, and human activity can all have a substantial impact on the abundance of pests in an area. Therefore, we're going to study each one of them in the context of ECCBC facility.

III.2.3.1 External influence

Fruital, is situated in the bustling industrial area of Rouïba, RN n°5 16013 Rouïba, Algiers, Algeria, operating within an environment that significantly influences pest dynamics. In this section, I am going to talk about the external factors affecting pest management at the facility.

The table III- summarizes the primary external factors influencing pest control at the ECCBC facility, detailing the causes and their corresponding effects or consequences.

Table III-2 External Influences on Pest Control at Fruital Facility

Location	Cause	Effect/Consequence
National Road 5	Increased human activity on the road	Leads to waste accumulation, attracting rodents, birds, and insects seeking food
Railway Line	Rail lines act as conduits for pests, facilitating their movement by transporting them	Introduces new pests to the area and spreads existing infestations
	The noise and vibrations from trains	Deters some pests but leads to waste accumulation, attracting rodents and insects
Rouiba Hospital and Habitats	Significant amounts of waste generated by hospitals and habitats	Attracts pests like rodents and flies if waste is not properly managed
East: Sarl Tango	The production and storage of beer, using grains	Attracts a variety of pests, including ants, birds, flies, stored product insects (SPIs), and rodents
	Waste products from beer production (e.g., spent grains)	Increases local pest population if waste is not managed, posing a higher risk of infestation to neighboring facilities
	Water and Humidity: Beer production involves significant water use, increasing humidity levels	Supports larger populations of pests like cockroaches and other moisture-loving insects

The analysis provided in the table highlights the importance of addressing external environmental factors in order to outline their effect on the facility. This will help to mitigate the related risks by addressing the causes.

III.2.3.2 Internal influence

ECCBC plant is divided into zones. In order to understand the influence of the internal factors, I decided to implement a dynamic evaluation criterion, based on the vulnerability of each zone and the three main attractions for pests (figure III-1) [19].

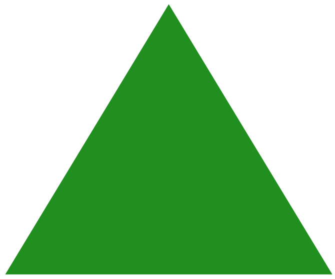


Figure III-1 Main attractions for pests

Before detailing the evaluation process, I will describe each criterion:

- Food Availability indicates the presence of food sources;
- Ease of Access indicates the availability of entry points such as cracks, gaps, and open doors or windows to enter facilities. Once inside, they can move freely and access nesting sites;
- Nest Suitability indicates the presence of suitable conditions for nesting. To make it clearer: it can include warm, dark, and undisturbed places where they can build nests and breed safely;
- Vulnerability is a parameter chosen specifically for food industry to indicate the sensitivity related to white zone where zero pest tolerance is required.

For each zone, we will assign a value of 1 or 0 for the applicability of the criteria. From that, you can get the total score of the zone, ranging from 0 to 4, indicating the level of influence on the pest dynamics. I recommend that the quality team conduct this step to ensure more accurate and reliable results.

A sample of the application is presented in (figure III-2), with the complete evaluation of the all the zones in table in the Appendix 3.

By analyzing the results, it is evident that the zones “Local soutirage ligne verre 30cl & 100cl” and “Local conditionnement ligne verre 30cl & 100cl” are the most attractive to pests, each with the highest score of 4. This indicates they meet all the criteria for pest attraction. Oppositely, the zones “Chambre froide,” “Local chimique,” “CO2,” “Gazoil,” and “Local Froid Ammoniac” have a score of 0, indicating minimal pest attraction.

ID	Nest Suitability	Food or water Accessibility	Ease of Access	Vulnerability	Score
ZONE SUD-OUEST	1	1	1	0	3
Dechetterie	0	1	1	0	2
Magasin PDR froid	0	1	1	0	2
Bureau zone sud	1	0	1	0	2
Atelier flotte	0	1	1	0	2
Magasin Marketing	1	0	1	0	2
Chambre froide + Local chimique +CO2+ Gazoil +Local Froid Ammoniac	0	0	0	0	0
Magasin Stockage préforme	1	0	0	0	1

Figure III-2 Sample of the internal zones evaluation.

III.2.4 Pests’ activity signs

In order to effectively manage pest control within the ECCBC facility, it is crucial to recognize the signs of pest activity. Therefore, I will detail them on the pests that we have chosen to work on (rodents, flies and mosquitoes.)

III.2.4.1 Rodents’ activity signs

The main rodents that I will be taken into consideration are rats and mice.

III.2.4.1.1 Rats’ activity signs

Detecting rats infestation signs is easier than spotting the actual rat, especially that these latter are nocturnal creatures. Below the most common signs:

- Brown Rat droppings are dark brown in a tapered, spindle shape - like a grain of rice.
- Grease and dirt on their bodies leaves smudges on surfaces.
- Black rats are agile climbers and often found in lofts. You might notice gnaw marks on wires, cabling or items stored in the loft.
- Brown rats are known for digging extensive burrow systems for shelter, food storage and nesting.
- Rats will shred available materials such as loft insulation, cardboard and other soft items to make nests.
- Rats leave foot and tail marks in dusty, less-used areas of buildings [20].

III.2.4.1.2 Mice’s activity signs

Mice tend to remain hidden during the day and forage for food from nightfall until dawn. Typical indicators of mouse activity include:

- Small and dark droppings (approx. 3 - 8 mm in length), scattered randomly, check inside or on cupboard tops or along skirting.
- Dark smears around holes or around corners.
- Body grease, combined with dirt and urine, builds up into small mounds, up to 4cm high and 1cm wide.
- Between partition walls, under floorboards, in false ceilings, basements and lofts.
- Check lofts, suspended ceilings, cavity walls, under floorboards and behind fridges, under stoves and in airing cupboards.
- Dusty environments such as unused lofts and basements can show up rodent tracks and tail marks.
- Live or dead mice
- Mice urinate frequently and their wee has a strong ammonia-like smell. The stronger the smell the closer you are to mice activity. This smell can linger for a long time (even after an infestation has been removed) [20].

III.2.4.2 Insects' activity signs

Identifying the presence of insects is crucial for effective pest management. Each type of insect leaves specific signs indicating their activity. Below are the primary indicators for ants, flies, and cockroaches.

III.2.4.2.1 Flies' activity signs

Typical indicators of flies activity include:

- Regular sightings of flies around your premises are a clear indication of a problem.
- Tiny dark spots, roughly the size of a pinhead, often seen on light fixtures or upper walls, are typically fly droppings.
- Maggots indicate a fly breeding site, which could be found in rubbish bins, decaying food, garden refuse, pet waste, or deceased pests like rats.
- Foul smells may indicate the presence of a dead rodent, likely to attract flies and maggots if left unattended [21].

III.2.4.2.2 Mosquitoes' activity signs

Detecting mosquito activity is essential for preventing potential health risks. Signs of mosquito infestation include:

- Itchy, red bumps on the skin are a common sign of mosquito bites
- Presence of mosquito larvae (wrigglers) in stagnant water sources such as ponds, birdbaths, and unused swimming pools

- Frequent sightings of adult mosquitoes, especially around dawn and dusk
- The distinctive high-pitched buzzing sound made by female mosquitoes
- Areas with standing water, where mosquitoes lay their eggs, can indicate potential breeding sites [22].

III.2.5 Pest control strategies

I gathered the information on pest control strategies from the formal pest control program of ECCBC (Appendix 5). Each strategy is designed to address specific aspects of pest management, from building maintenance to eradication measures (Appendix 4).

While these strategies form a solid foundation for pest control, ECCBC's traditional approach requires significant improvements to meet modern standards. The current methods lack integration of advanced technologies, such as predictive modeling, data analysis, and an automated interface, and a cohesive system that combines these strategies effectively.

The next step will involve providing recommendations to modernize and enhance these pest control strategies, ensuring continuous improvement, effectiveness, and alignment with best practices in pest management.

III.2.6 Recommendations

As ECCBC continues to grow, adding new production lines and increasing its output, the complexity of maintaining a pest-free environment also increases. It is essential to evolve the pest control practices to keep up with this growth and ensure food safety. However, while new technologies are necessary for better control of the situation, they will not be effective without a comprehensive system that links our strategies.

Appendix 6 highlights the potential of integrating new technologies. Yet, the primary issue lies in the absence of a cohesive pest management system. A proper pest management system should start with thorough monitoring. We need an automated data collection system that not only gathers data but also analyzes it. This data should then be processed to enhance our annual pest control program. Each time data is collected, it must be analyzed to understand the situation accurately and set precise limits for action. Then, a digital reporting should be implemented for quicker communication.

In order to address these issues, the starting point is to process the data. I will provide a detailed approach using the data on rodents consuming baits as a case study. This approach will involve:

(i) Preprocessing the data, (ii) Creating a template for data collection, (iii) Analyzing the data, (iv) Exploring the findings, and (v) Discussing the results.

III.3 Consumed baits data preprocessing

I will use a basic approach of data preprocessing (figure III-4) to transform the raw data into a clean and organized format for further analysis.

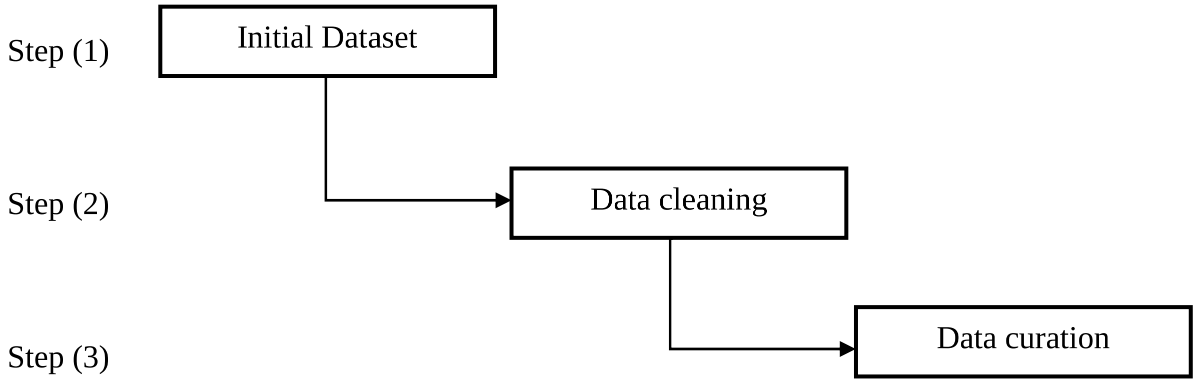


Figure III-3 Diagram of data preprocessing

The process begins with obtaining the initial dataset, which consists of raw data collected through our pest management activities, particularly focusing on rodents consuming baits. The first step involves gathering all relevant data, including the location of traps, the number of pests caught, and the dates and times of these events. Next, I will intervene during the data-cleaning phase to ensure the dataset is accurate and reliable. This step includes removing unnecessary or irrelevant information, correcting errors, and ensuring consistency across the dataset. For instance, duplicate entries, incorrect dates, or irrelevant columns will be identified and removed. Finally, the data curation step will organize and structure the cleaned data, making it ready for analysis. This involves standardizing the data format, ensuring completeness, and preparing it for the creation of a data collection template. By following this structured approach, we will ensure our data is accurate and reliable, paving the way for detailed analysis and comprehensive insights into our pest management system.

III.3.1 Initial Dataset

Rayane Hygiene is a subcontractor of ECCBC, they specialize in treating rodents and insects, such as flies and cockroaches.They establish an annual pest control program, detailing the dates of all visits and eradication treatments throughout the year. The primary purpose of these visits is to detect any abnormalities and collect data using various monitoring devices, including electronic insect killers, insect glue traps, mechanical traps, and snap traps. Each device is uniquely numbered for tracking purposes.

The subcontractor also maintains a log that includes the number of each device, additional information about the subcontractor company for emergencies and all relevant safety precautions, as seen in the picture below (figure III.4 & 5).

Figure III-5 Electric insect killer

Figure III- III-4 Rodent trap

For insect monitoring devices, the number of dead insects found in each device is recorded and for rodent monitoring, the amount of consumed chemical bait is measured. This data is compiled into a report and submitted to the Metrology and Quality Monitoring Manager. The manager analyzes this data and organizes it into two tables;

- ***i.*** The first table outlines the number of consumed traps for each zone for a single visit (table III-3);
- **ii.** The second table provides detailed information on the ID of each trap and specifies the type of consumption observed, whether it was total or partial (table III-4).

Complete versions of these tables are provided in Appendix 7.

Table III-3 Sample of the consumed traps table done on 02/03/2023

Endroits Controlés	Opération effectuées	1ère Contrôle d'efficience d'appattage	2ème Contrôle d'efficience d'appattage	3ème Contrôle d'efficience d'appattage	4ème Contrôle d'efficience d'appattage	5ème Contrôle d'efficience d'appattage	Vérification d'efficacité des contrôles (Metrology & Quality Monitoring Manager)
	Dératisation	Date:	Date: 02/03/2023	Date:	Date:	Date:	
Ancienne ligne canette coté Droite			0				OK
Ancienne ligne canette coté Gauche			0				OK
Coté murs extérieur (Can. Ancien)			0				OK
Local stockage concentré partie sèche			0				OK
Local Sucre extérieur			0				OK
Coté Station de pompage N° 01			0				OK
Couloir annexes			0				OK
Entrée Stockage Préforme PET 10/10			0				OK
Sous station Electrique			0				OK
Conditionnement PET 10/10			0				OK
Conditionnement Ligne Verre 30 cl			0				OK
Sortie Conditionnement PET 10/14			0				OK
Local Soufflage PET 10/14			0				OK

Table III-4 Sample of the detailed consumed traps table done on 02/03/2023

Endroits Controlés	N° des boites Consommées	ETAT DES APPATS	OBSERVATION	ACTION
Ancienne ligne canette coté Droite				
Ancienne ligne canette coté Gauche				
Coté murs extérieur (Can. Ancien)				
Local stockage concentré partie sèche				
Local Sucre extérieur				
Coté Station de pompage N° 01				
Couloir annexes				
Entrée Stockage Préforme PET 10/10				
Sous station Electrique				
Conditonnement PET 10/10				
Conditionnement Ligne Verre 30 cl				
Sortie Conditionnement PET 10/14				

I discovered that an individual Excel file was created for each visit, resulting in approximately 24 files per pest annually. Each file contained at least 61 data points, leading to around 1,464 data entries per year. However, this crucial data was neither treated nor analyzed, rendering the task inefficient and unnecessary. Despite this inefficiency (as mentioned in III.5), the task incurs a significant cost of approximately 10,587 USD annually.

To ensure this data gets the weight it deserves and becomes useful, it is essential to implement a robust data management and analysis system that can optimize pest control practices and resource allocation effectively.

III.3.2 Data cleaning

To enhance the quality of our dataset, I removed redundant information. Starting with controlled zones that showed no signs of bait consumption or captured insects, I then addressed control entries with no data, indicating they were empty. Finally, I refined the graphic representations for each zone that lacked adequate treatment. This step may be straightforward, but in fact, it was actually time-consuming due to the extensive volume of the initial data.

III.3.3 Data curation

Data curation involved integrating data from various sources into a single, cohesive dataset. Ensuring consistency in data formats and structures across sources was paramount. In this case, I would be working on the rodents file from 2023 to create a dynamic template.

III.3.3.1 Monitoring visits and the rodent control operations

For the 2023 data, I began by organizing the monitoring visits and rodent control operations, as illustrated in the table III-5.

Table III-5 Table representing monitoring visits and the rodent control operations

N° Visite	1st control	2nd control	3rd control	4th control
1	09/02/2023	02/03/2023	28/03/2023	/
2	17/04/2023	07/05/2023	28/05/2023	/
3	18/06/2023	27/06/2023	/	/
4	16/07/2023	27/07/2023	/	/
5	17/08/2023	27/08/2023	04/09/2023	/
6	17/09/2023	27/09/2023	/	/
7	15/10/2023	06/11/2023	27/11/2023	/
8	17/12/2023	08/01/2024	15/01/2024	28/01/2024

(green)	**Efficiency control**
(yellow)	**Deratisation operation**

III.3.3.2 Yearly data organization

Appendix 8 outlines the collection rodent trap consumption data for each control operations across various locations within the facility. It is organized into three main columns representing the first, second, and third operations. Each operation is further divided into sub-columns: "The number of consumed baits" and "Intern verification ".

"Zone": This column lists all the specific locations within the facility where the rodent control operations / visits are conducted.

"The number of consumed baits": This sub-column records the number of bait boxes that have been consumed during each operation. The value "0" indicates no consumption, while any other number would indicate the amount consumed.

"Intern verification": This sub-column shows the internal verification status for each location. The term "Validated" indicates that the internal verification process has been completed and approved.

The final row summarizes the total number of consumed bait boxes and the overall success of the verification process for each operation.

III.3.3.3 The Optimization of the table III-4

As observed, Table III-4 includes numerous zones with zero bait consumption, which results in unnecessary data and gaps. Yet, we only need to focus on the zones where the number of consumed baits is greater than zero. To address this, I developed a function named "Valid" in VBA. It main function is to extract the relevant zones with bait consumption above zero. The figure III-7 illustrates the code representing this latter.

```vba

Option VBASupport 1
Option Explicit

Public Function valid(noms As Range, liste_1 As Range, liste_2 As Range, liste_3 As Range) As Variant
'The function valid is defined to take four arguments: noms, liste_1, liste_2, and liste_3. These arguments are expected to be ranges (sets of cells) in a spreadsheet.

    Dim lnbval As Long, i As Long, j As Long
    'lnbval: A Long variable to store the number of rows in the noms range.
    'i, j: Long variables used as loop counters.

    Dim v_valid() As Variant
        'v_valid(): A dynamic array of Variant type to store the valid names.

    lnbval = noms.Rows.Count
     ' Determine the number of names (assuming the range is a single column)

    ReDim v_valid(1 To lnbval, 1 To 1)
     ' Initialize the array based on the number of names

    j = 1
      'j is initialized to 1 and will be used to track the position in the v_valid array.
    For i = 1 To lnbval
    'The loop runs from 1 to lnbval, iterating over each row in the noms range.

        If liste_1.Cells(i, 1).Value > 0 Or liste_2.Cells(i, 1).Value > 0 Or liste_3.Cells(i, 1).Value > 0 Then
            v_valid(j, 1) = noms.Cells(i, 1).Value
            'Inside the loop, the function checks if any of the cells in liste_1, liste_2, or liste_3 for the current row (i) have a value greater than zero.
            j = j + 1
            'If the condition is met, the corresponding name from noms is stored in v_valid, and j is incremented by 1.
        End If
    Next i

    ' Resize the array to match the number of valid entries

    valid = v_valid
     ' Return the array of valid entries
End Function

```

Figure III-7 The VBA program for the function Valid

Using this function will reduce the table III-4

{=VALID(B9:B69;C9:C69;E9:E69;G9:G69)}

B	C	D	E	F
DETAILLE DE CONSOMMATION D'APPATAGE				
SECTEUR :				
Endroits Contrôlés	**N° des boites Consommées**	**ETAT DES APPATS**		**ACTION**
zone Sud-Ouest (Coté Hôpital)				
Entre Accés3&4 Nouveau Magasin (intérieur)				

Figure III-6 Output of the function VALID

III.3.4 Processed Dataset

Using the template, I created before I have treated the data from 2018, even though I have the one from 2013 for the simple reason of the changing number of traps and insect killers, since 2018 I have a relatively stable number. Here are the Data for consumed bait, which are the main case of study:

Table III-6 the monthly number of consumed baits from 2018 to 2023

	J	F	M	A	M	J	J	A	S	O	N	D
2018	1	3	2	0	6	5	4	7	8	24	5	2
2019	0	2	4	4	6	12	5	16	7	24	2	13
2020	0	4	3	15	10	7	3	35	17	19	3	9
2021	1	7	5	5	0	31	12	9	0	3	0	0
2022	4	5	1	0	0	21	12	7	4	4	0	1
2023	0	0	2	2	7	4	0	1	10	3	20	0

III.3.5 Analysis of Bait Consumption

The chart below (figure III-8) displays the monthly consumption of baits from January 2018 to November 2023. The data reveals several distinct trends and patterns in bait usage over this period, offering insights into the periodicity and factors influencing bait consumption.

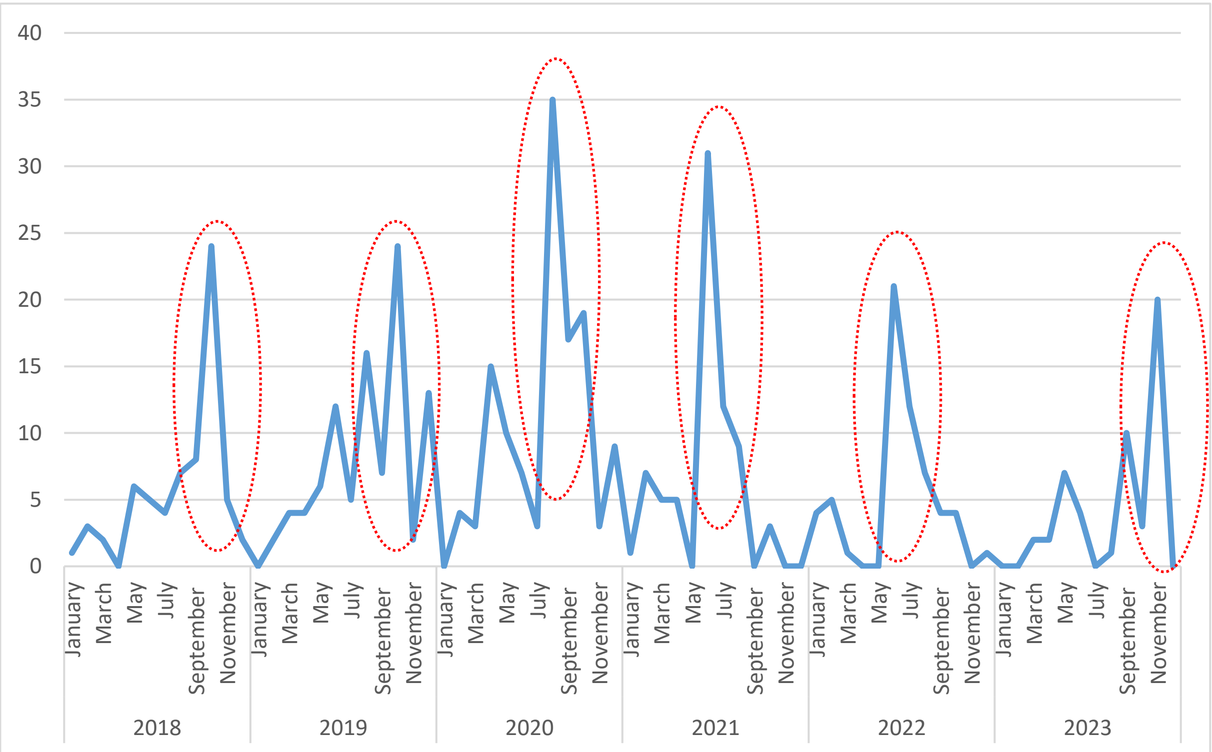


Figure III-8 Analysis of Biannual Trends in Bait Consumption from 2018 to 2023

The data spans nearly six years, with monthly intervals providing a detailed view of bait consumption trends. The consumption values fluctuate significantly over time, indicating periods of both high and low bait usage.

Several prominent peaks in bait consumption are evident throughout the chart. The most notable spikes occur in:

July 2018: This peak represents a surge in pest activity during the summer (warm) months.
June 2019: Similar to the previous year, this peak is due to seasonal factors, with warmer weather contributing to higher pest activity.
April 2020: This earlier peak compared to previous years indicates a response to specific environmental conditions (attractions figure III-1).
June 2021 & 2022: These two peaks suggest another summer-related increase in pest activity, requiring more bait consumption.
October 2023: This later spike in the year is due to a delay in seasonal pest activity

These peaks represent periods where bait consumption surged, likely in response to increased pest activity, specific environmental conditions that necessitated higher bait usage or there was a problem with the structure of the building [7].

Analyzing the periodicity of the data, a rough annual cycle emerges, indicating a pattern of peaks approximately every 12 months. The largest peaks often occur around mid-year (June to August) and sometimes at the end of the year (October to December).

The bait consumption data shows a periodic trend with a cycle of approximately six months. The highest consumption typically occurs during the summer and sometimes toward the end of the year, aligning with seasonal increases in pest activity. While the exact timing of the peaks can vary, the overall pattern indicates a significant rise in bait usage during these periods. This analysis underscores the importance of preparing for higher bait consumption during these peaks to effectively manage pest populations.

In the next section, I will investigate whether the influence of temperature on the trap consumption.

III.4 Exploratory Data Analysis on Rodent consumed baits

III.4.1 Bait consumption and average temperatures dataset

The line chart illustrates the bait consumption and average temperatures from 2018 to 2023 [23].

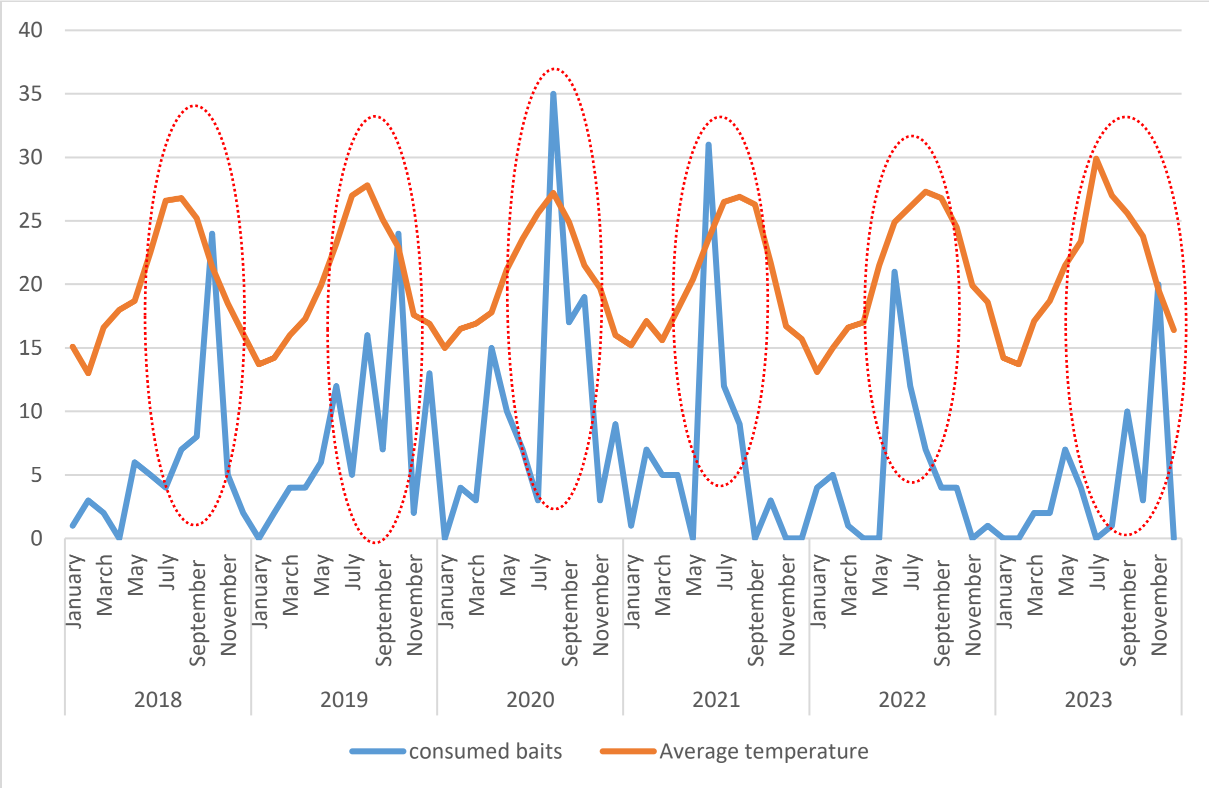


Figure III-9 Bait consumption and average temperatures from 2018 to 2023

The seasonal trend is evident, with bait consumption typically peaking during the warmer months (June to September) and decreasing during the colder months (December to February). This pattern suggests a strong correlation between higher temperatures and increased bait consumption. Each year, peaks in bait consumption often coinside with the highest average temperatures, indicating that warmer weather might drive higher bait usage. However, certain anomalies, such as the unusually high bait consumption in October 2018 and August 2020, suggest that factors other than temperature might also play a role. Notably, 2022 and 2023 show some deviations from the pattern, with increased bait consumption in typically colder months like December and November, respectively.

Overall, the line chart highlight a general trend where warmer temperatures lead to higher bait consumption, with some instances of additional factors influencing this relationship.

Still this is only the visual interpretation; I shall now dive into the numerical aspect by applying Spearman's correlation test on bait consumption and average tempratures.

III.4.2 Spearman's Rank Correlation test

Spearman's correlation assesses the strength and direction of a monotonic relationship between two variables. It is clear that the relationship is not linear but the variables tend to change together in a consistent way because of that choosing the Spearman's Rank Correlation is the most adequate.

III.4.2.1 Spearman's Rank Correlation Coefficient (ρ) formula

Spearman's Rank Correlation Coefficient (**ρ**) is calculated manually as (III-1)

$$\rho = 1 - \frac{6\sum_{1}^{i} di^2}{n(n^2-1)} \qquad \text{(III-1)}$$

Where:

- di is the difference between the ranks of the corresponding values of the two variables.
- n is the number of pairs of values.

III.4.2.2 t-value formula

Once we have ρ, the t-value can be calculated using (III-2)

$$t = \frac{\rho\sqrt{n-2}}{\sqrt{1-r^2}} \qquad \text{(III-2)}$$

Where:

- $\boldsymbol{n}$ is the number of observations.
- $\boldsymbol{\rho}$ is the Spearman's rank correlation coefficient.

III.4.2.3 p –value calculation

We use the t-statistic and degrees of freedom (df) to look up the value in a t-distribution table [25].

III.4.2.4 Calculate the results

In order to facilitate and get reliable results, I will be interested in calculating the correlation coefficient, and the p-value using a python code.

Figure III-10 details the associated code.

```python
import pandas as pd
from scipy.stats import spearmanr
import numpy as np

# Recreate the data based on the provided image
data = {
    'Consumed_baits': [
        1, 3, 2, 0, 6, 5, 4, 7, 8, 24, 5, 2, 0, 2, 4, 4, 6, 12, 5, 16, 7, 24, 2, 13, 0, 4, 3, 15, 10, 7, 3, 35, 17, 19, 3, 9, 1, 7, 5, 5, 0, 31, 12, 9,
    ],
    'Temp_Max_moyennes': [
        17, 15, 19, 21, 21, 25, 29, 29, 27, 24, 21, 18, 16, 16, 18, 20, 22, 26, 29, 30, 27, 26, 20, 19, 17, 19, 19, 20, 23, 26, 28, 29, 27, 24, 22, 18,
    ],
    'Temp_moyennes': [
        15, 13, 17, 18, 19, 23, 27, 27, 25, 21, 19, 16, 14, 14, 16, 17, 20, 23, 27, 28, 25, 23, 18, 17, 15, 17, 17, 18, 21, 24, 26, 27, 25, 22, 20, 16,
    ],
    'Temp_Mini_moyennes': [
        13, 11, 14, 15, 17, 21, 25, 25, 23, 19, 16, 14, 12, 12, 14, 15, 17, 21, 25, 26, 23, 20, 15, 15, 13, 14, 15, 16, 19, 21, 23, 25, 23, 19, 18, 14,
    ]
}

# Create a DataFrame
df = pd.DataFrame(data)

# Calculate Spearman's rank correlation coefficient
spearman_corr_high, p_value_high = spearmanr(df['Consumed_baits'], df['Temp_Max_moyennes'])
spearman_corr_avg, p_value_avg = spearmanr(df['Consumed_baits'], df['Temp_moyennes'])
spearman_corr_low, p_value_low = spearmanr(df['Consumed_baits'], df['Temp_Mini_moyennes'])

# Print the results
print(f"Spearman's rank correlation between Consumed Baits and Max Temperature: {spearman_corr_high}, p-value: {p_value_high}")
print(f"Spearman's rank correlation between Consumed Baits and Average Temperature: {spearman_corr_avg}, p-value: {p_value_avg}")
print(f"Spearman's rank correlation between Consumed Baits and Min Temperature: {spearman_corr_low}, p-value: {p_value_low}")
```

Figure III-10 Python code for the generation of spearman correlation value, t-value and p-value

III.4.2.5 Results and discussion of Spearman’s Rank Correlation test

The table below summarizes the Spearman's rank correlation coefficient, and p-value for the relationships between consumed baits and different temperature measures. These values indicate the strength and significance of the correlations.

Table III-7 The Correlation coefficient and P-value

Spearman's rank correlation between Consumed Baits & Temperature	Average max temperature	Average Temperature	Average min Temperature
Correlation coefficient (ρ)	0.43	0.44	0.45
p-value	0.0001	0.0001	7.27×10^{-5}

The calculated Spearman's rank correlation coefficients (ρ) indicate a weak positive correlation. Since the correlation coefficients are not close to 1, the relationship between consumed baits and temperature measures is not strongly linear. In the other hand, the positive Spearman's correlation coefficients indicate that as temperatures increase, the number of consumed baits tends to increase as well, albeit weakly.

The p-values are all below 0.05; this means that the observed correlations are statistically significant. This means that the positive monotonic relationships between consumed baits and temperature measures are unlikely to be due to random chance. The results indicate a weak but statistically significant positive monotonic relationship between consumed baits and temperature measures.

While the correlation results indicate a relationship between temperatures and bait consumption, the non-linear nature of this relationship suggests that simple linear regression models are inadequate. Therefore, I will use the second characteristic of my data: the seasonal patterns with annual cycles.

To create a reliable prediction, I will use a personalized model to forecast rodent bait consumption using a combination of Seasonal-Trend decomposition using LOESS (STL), AutoRegressive Integrated Moving Average (ARIMA), and Exponential Smoothing models.

III.5 Prediction of consumed baits for the next two years

For the prediction of rodents consumed baits, I have chosen to employ a combination of three models: Seasonal and Trend decomposition using Loess (STL), AutoRegression Integrated Moving Average (ARIMA), and Exponential Smoothing. This selection is based on careful analysis and is not random.

The data for consumed baits (figure III-8) exhibits a clear seasonal pattern with a cycle of 12 months. This periodicity suggests that the same pattern repeats annually. My previous attempts to forecast using simple regression, as discussed in III.4.2.4, have been unsuccessful. Therefore, I will treat the data as a time series.

My method begins with the STL decomposition, which breaks down the time series into its trend, seasonal, and residual components:

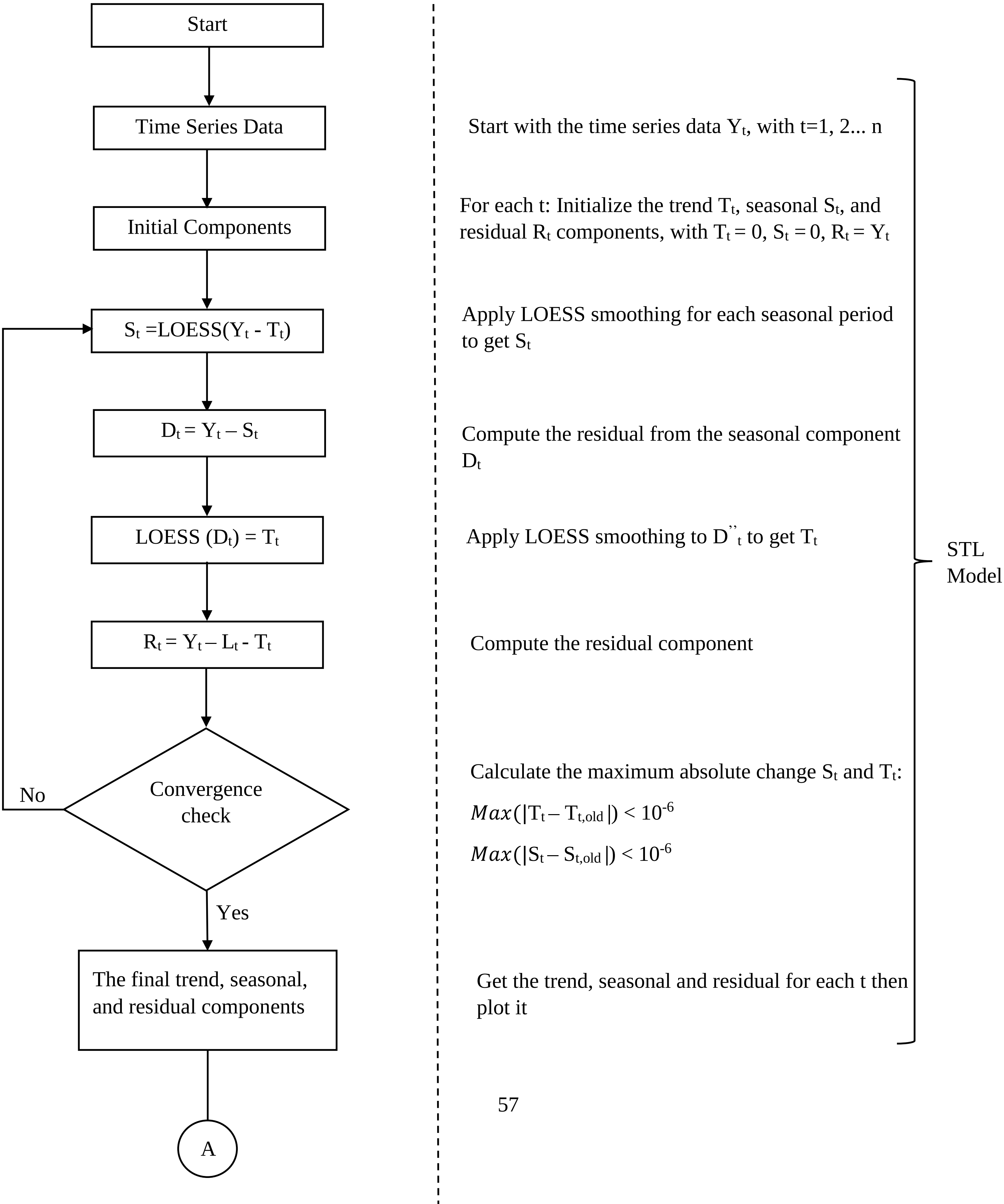
- **i.** For the trend Component, I used Exponential Smoothing. This method smooths out the short-term fluctuations and highlights the long-term trend;
- **ii.** For the seasonal component, I assume the seasonal pattern from the last year will repeat.
- **iii.** Residual Component: I apply the ARIMA model to the residual component, which includes autoregressive (AR) and moving average (MA) components to capture different dependencies in the data.

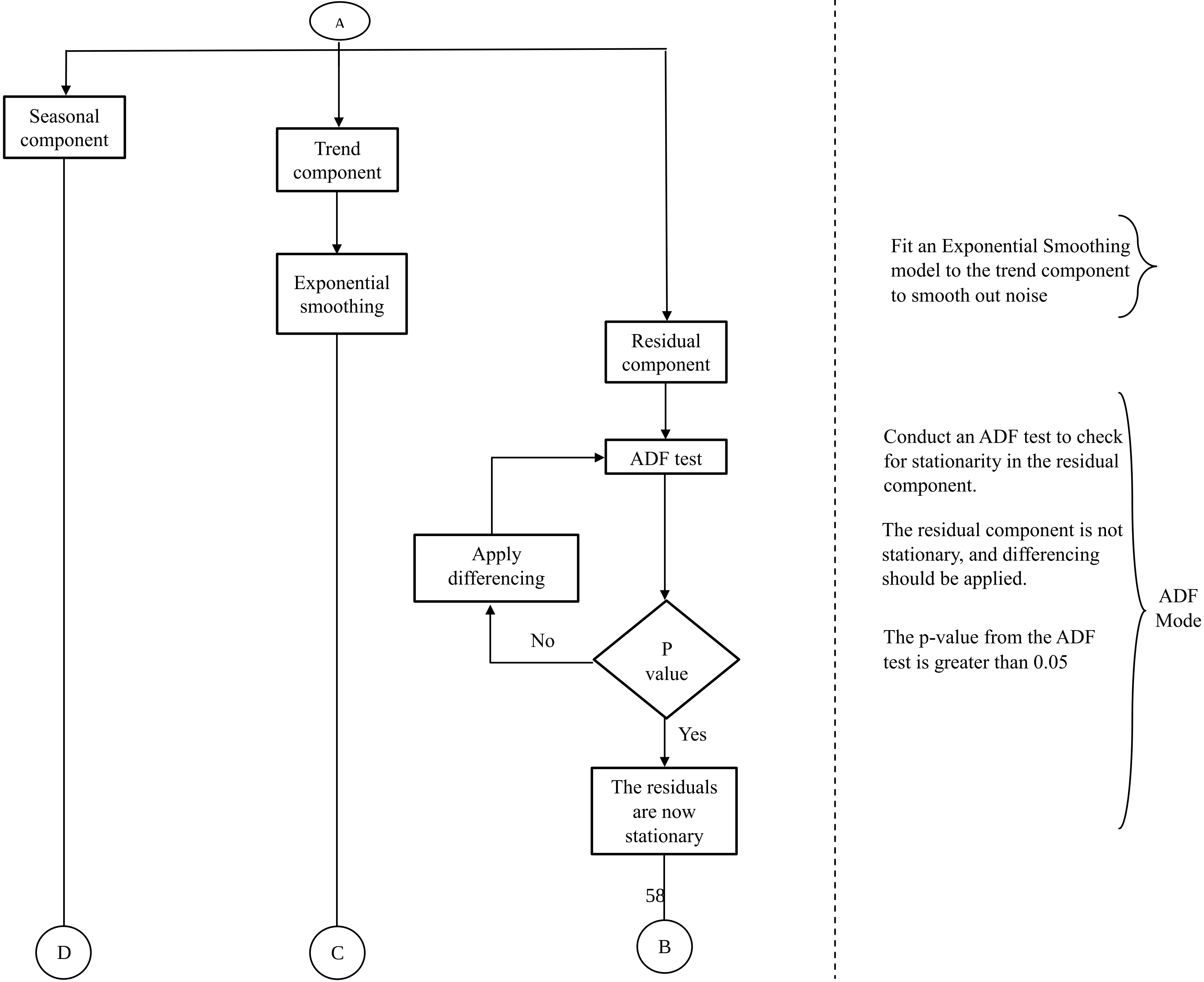
This combined approach typically results in better forecast accuracy compared to using ARIMA alone on raw data. I will start by outlining the steps of the STL, ARIMA, and Exponential Smoothing models and explain how I combined them. I will then provide the mathematical formulas for each step. Finally, I will develop a Python program to implement this process, as the formulas are quite complex.

III.5.1 Prediction model process

The following diagram (figure III-11) illustrate the prediction model process. We start with the decomposition of the time series data into its trend, seasonal, and residual components using STL. After that, we use Exponential Smoothing to forecast the trend component. For the seasonal component, we assume the seasonal pattern from the last year would repeat. Following that, we work on the residual component. We apply first the Augmented Dickey-Fuller (ADF) test to check for stationarity. If the residuals are not stationary, apply differencing. Once we achieve stationarity, we adopt the used parameters to model the residual component using

ARIMA. Next, we evaluate the fitted model using residual analysis and AIC/BIC values. Finally, we combine the forecasts from the trend, seasonal, and residual components to get the final forecast.




A
Seasonal component
Trend component
Exponential smoothing
Residual component
ADF test
Apply differencing
P value
No
Yes
The residuals are now stationary
D
C
B
Fit an Exponential Smoothing model to the trend component to smooth out noise
Conduct an ADF test to check for stationarity in the residual component.
The residual component is not stationary, and differencing should be applied.
The p-value from the ADF test is greater than 0.05
ADF Mode

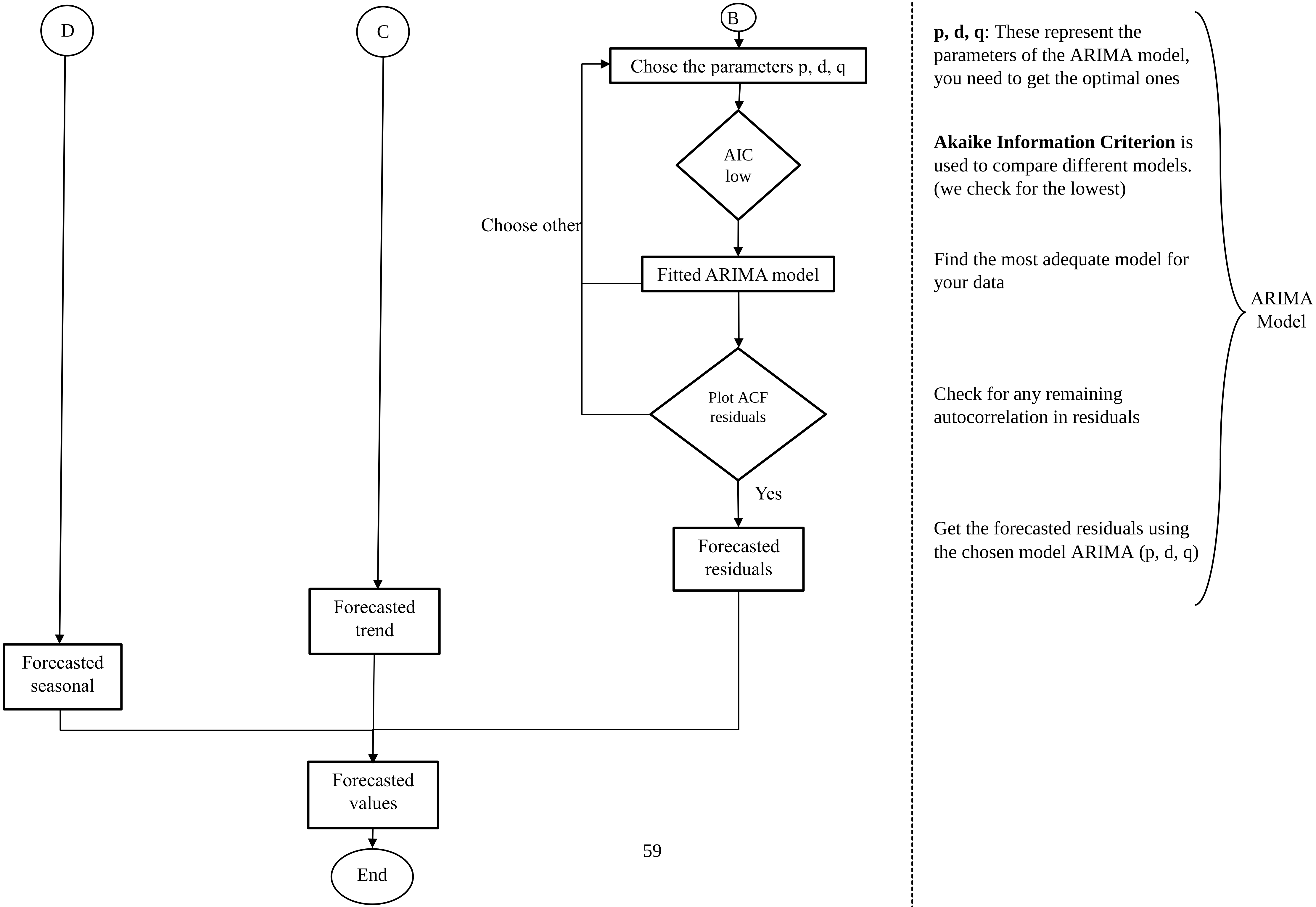


Figure III-11 Prediction model process

In the next section, I will present the mathematical formulas for each component, and how to integrate these methods into a Python program. This approach not only enhances our understanding of the data's underlying patterns but also provides a robust framework for making precise and reliable forecasts.

III.5.2 Mathematical formulation for STL, ADF, ARIMA and Exponential smoothing

In the subsequent section, I will provide the mathematical formulations for the Seasonal and Trend decomposition using Loess, Augmented Dickey-Fuller (ADF), Exponential smoothing, and ARIMA models. This will include the equations necessary for the decomposition of time series data into its constituent components, the testing for stationarity, and the modeling of autoregressive integrated moving average processes.

III.5.2.1 STL decomposition

STL (Seasonal and Trend decomposition using Loess) is a method for decomposing a time series into three components:

- Seasonal component (S_t): Captures the repeating patterns at fixed frequencies
- Trend component (T_t): Represents the long-term progression of the series
- Residual component (R_t): The noise or irregular component

The STL decomposition can be represented as:

$$Y_t = T_t + S_t + R_t \quad \dots\dots\dots\dots\dots\dots.(III\text{-}3)$$

III.5.2.2 Trend component formula T_t

The trend component represents the long-term progression in the data. It is obtained using a Loess smoother, which is a locally Iighted regression.

$$T_t = LOESS(Y_t - S_t) = \sum_{i=1}^{k} w_i T_{t+i} \dots\dots\dots\dots\dots\dots\dots\dots. \quad (III\text{-}4)$$

Where:

- T_t is the trend component
- k half width of the smoothing window, for monthly data with yearly seasonality : k =12
- S_t is the seasonal component
- Y_t is time series value

- w_i is the weight , it is calculated as follow :

$$w_i = (1 - \left|\frac{x_i - x_t}{d}\right|^3)^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{(III-5)}$$

Where d is the furthest distance between t and the k[th] point of the neighborhood, x_i is the neighbor point, x_t target point

III.5.2.3 Seasonal component formula S_t

The seasonal component captures the repeating patterns at fixed frequencies. It is also obtained using a Loess smoother applied to the detruded series.

$$S_t = LOESS(Y_t - T_t) = \sum_{i=1}^{p-1} w_i S_{t+i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(III-6)}$$

With:

- T_t is the trend component
- p is the periodicity
- S_t is the seasonal component
- Y_t is time series value

III.5.2.4 Residual component formula R_t

The residual component represents the remaining part of the time series after removing the trend and seasonal components. It is essentially the noise or irregular component in the data [23].

- w_i is the weight (see eq III-7**)**

$$R_t = Y_t - (T_t + S_t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{(III-8)}$$

III.5.2.5 Augmented Dickey-Fuller (ADF) test formula

The ADF test is used to check for the presence of unit roots in a time series sample, which helps determine if the series is stationary [24] [25]. The formula for the ADF test is

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p} \sigma_i \Delta y_{t-i} + \varepsilon_t \ldots\ldots\ldots.\ldots \text{(III-9)}$$

With:

- Δy_t is the first difference of the series, $y_t - y_{t-1}$

- α is a constant
- βt is the coefficient on a time trend (if included)
- γy_{t-1} is the lagged level of the series
- $\sigma_i \Delta y_{t-i}$ are the p lagged differences of the series, with σ_i being the coefficients [26]
- ε_t is the white noise error term
- p is the number of lagged differences included in the model

III.5.2.6 ARIMA formula

AutoRegressive Integrated Moving Average (ARIMA) models are widely used for time series forecasting. They combine autoregressive (AR) and moving average (MA) components and can include differencing (I) to make the time series stationary. The parameters p, d, and q are used to specify the ARIMA model, where p is the number of lag observations, d is the degree of differencing, and q is the size of the moving average window [27] [28].

The forecasting formula for an ARIMA model can be generalized as follows:

$$\widehat{Y_{t+k}} = \mu + \sum_{i=1}^{p} \phi_i \widehat{Y_{t+k-\iota}} + \sum_{i=1}^{q} \theta_i \widehat{\varepsilon_{t+k-\iota}} \ldots\ldots\ldots\ldots. \text{(III-10)}$$

Where:

- Y_{t+k} is the forecast value k steps ahead.
- μ is the mean of the series if it is not zero-centered.
- The ϕ terms are the coefficients from the AR part.
- The θ_i terms are the coefficients from the MA part.
- The ε terms are the residuals (errors).

III.5.2.7 AIC formula

The Akaike Information Criterion (AIC) is a measure used for model selection in statistical analysis. It evaluates models based on their goodness of fit while penalizing for the number of parameters to avoid overfitting. The AIC is calculated using the following formula:

$$AIC = 2k - 2\,ln\,L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(III-11)}$$

Where:

- k is the number of parameters in the model.
- L is the maximum value of the likelihood function for the model : $L = e^{\log\_likehood}$

III.5.2.8 Exponential smoothing formula

Exponential Smoothing, particularly Holt's Linear Trend Model, is used to forecast the trend component of a time series due to its effectiveness in capturing and projecting linear trends in data. Holt's Linear Trend Model uses the following equations:

$$\widehat{Y_{t+k}} = l_t + kb_t \quad \text{..............................(III-12)}$$

Where:

- α is the smoothing parameter for the level.
- β is the smoothing parameter for the trend.
- l_t is the level component at time t , where $l_t = \alpha y_t + (1 - \alpha)(l_{t-1} + b_{t-1})$
- b_t is the trend component at time t , where $b_t = \beta(l_t - l_{t-1}) + (1 - \beta)\, b_{t-1}$
- Y_{t+k} is the forecast value k periods ahead.

III.5.3 Python implementation of complex time series models: STL, ADF, and ARIMA and Exponential smoothing

In the next sections, I will make a detailed dissection of the Python code developed to represent the previous forecasting process. Luckily for us, Python has libraries specialized in the implementation of this type of forecasting. They will not only save us considerable time and energy but also enhance the reliability of our results. The program will generate a series of plots and numerical results that will be examined in a successive analysis phase. Furthermore, I will discuss the final forecasting results in order to improve the rodent control program.

III.5.3.1 Dataset initialization and preprocessing

To start, I loaded the dataset containing monthly counts over a span of six years, from January 2018 to December 2023. The data is structured into a Pandas DataFrame with a 'Date' index and a 'Count' column.

```
# Load data
data = {
    'Date': pd.date_range(start='2018-01-01', periods=72, freq='M'),
    'Count': [
        1, 3, 2, 0, 6, 5, 4, 7, 8, 24, 5, 2, 0, 2, 4, 4, 6, 12, 5, 16, 7, 24, 2, 13, 0, 4, 3, 15, 10, 7,
        3, 35, 17, 19, 3, 9, 1, 7, 5, 5, 0, 31, 12, 9, 0, 3, 0, 0, 4, 5, 1, 0, 0, 21, 12, 7, 4, 4, 0, 1,
        0, 0, 2, 2, 7, 4, 0, 1, 10, 3, 20, 0
    ]
}
df = pd.DataFrame(data)
df.set_index('Date', inplace=True)

# Use only the last three years of data (36 months)
df_last_three_years = df[-36:]
```

Figure III-12 Dataset Initialization and Preprocessing code

The dataset then filtered to include only the last three years of data. This step is crucial for focusing the analysis on the most recent and relevant period, which is necessary in our case because of the change of the general placement of traps in the facility.

III.5.3.2 Time series decomposition using STL model

Once I have prepared our time series data, the next step involves decomposing it into its constituent components: trend, seasonal, and residual. This is achieved using the STL (Seasonal-Trend decomposition using LOESS) method. The following code snippet demonstrates how to perform STL decomposition on our dataset and extract the different components.

```
# Decompose the time series
stl = STL(df_last_three_years['Count'], seasonal=11)
result = stl.fit()

# Plot the decomposed components
result.plot()
plt.show()
```

Figure III-13 Time series decomposition using STL model code

In the code above, I initialized the STL decomposition with the last three years of data and specified a seasonal period of 11. If this model is further used, I should specify that seasonal period must be an odd number due to symmetrical reasons in LOESS method (centering the smoothing window on each data point).

The ***(fit)*** method performs the decomposition, and I then plot the resulting components to visualize the trend, seasonal, and residual parts of the time series. By extracting these components, I can separately analyze each part to gain deeper insights into the behavior of the data.

III.5.3.3 Analysis of decomposed time series

The ***Figure III-17*** illustrates the decomposition of a time series dataset monitoring the consumption of baits across a three-year span, outlining three primary components: trend, seasonal, and residual.

The trend component exhibits a gradual downward progression over the three years. Initially, bait consumption is notably high, but it steadily decreased. This decline is attributed to the improvement of pest control strategies.

The seasonal component reveals recurring fluctuations in bait consumption, with cycles approximately every 11 months. Peaks in this component correspond to heightened periods of bait usage. These seasonal variations may be associated with pest reproductive cycles (hormonal animals), and other periodic influences on pest behavior and so, by extension, bait consumption.

Lastly, the residual component clusters around zero, indicating that the predominant structure of the data is adequately represented by the trend and seasonal components. Nonetheless, there are instances of outliers and elevated deviations, signaling occasional irregularities in bait consumption.

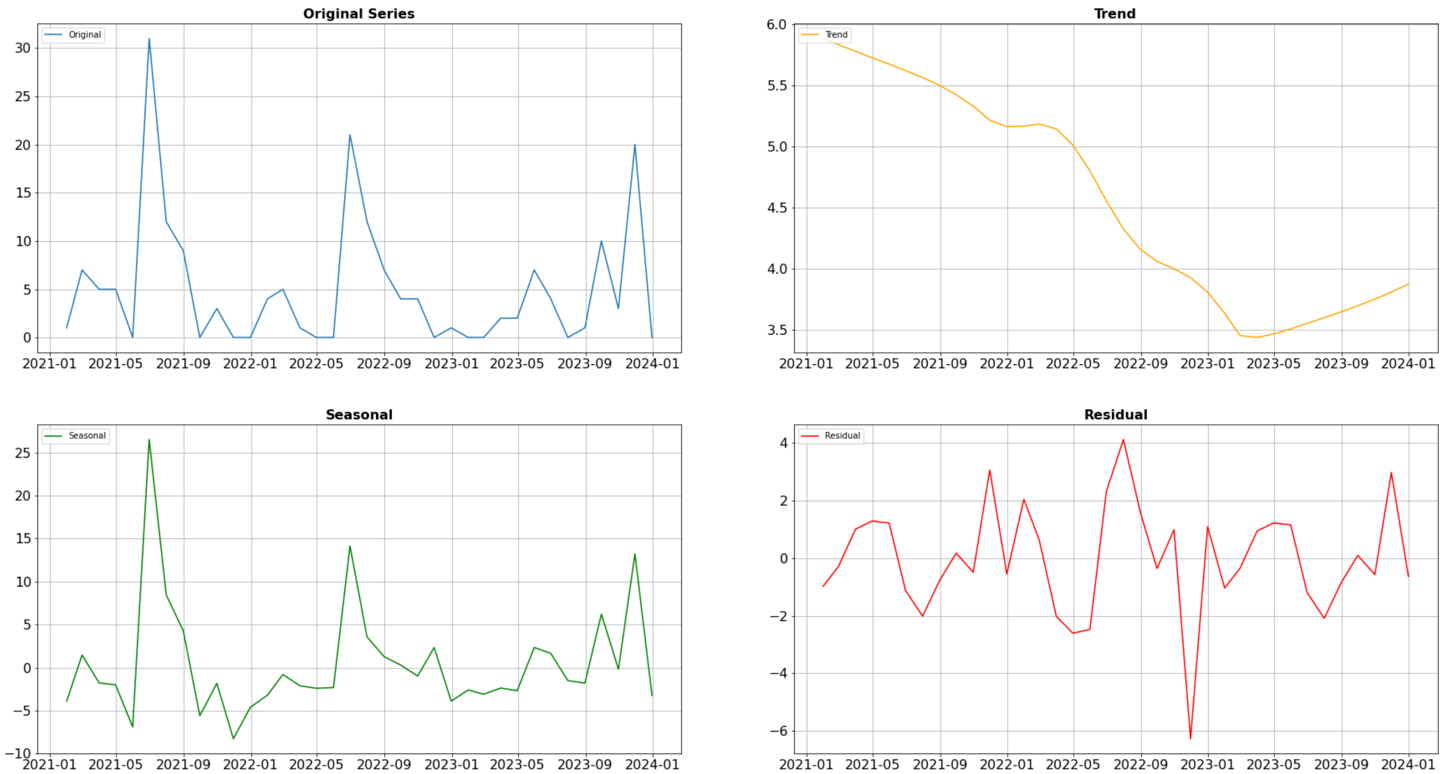


Figure III-14 STL decomposed time series: visualizing the trend, seasonal and residual

the next step is to work on the residuals stationarity before applying predictive models.using the ADF test

III.5.3.4 Stationarity testing using ADF and differencing

To check for stationarity, I used the Augmented Dickey-Fuller (ADF) test. If the residuals are non-stationary, I apply differencing to stabilize the mean of the residuals series. The following code snippet (Figure III-18) demonstrates this process:

```
# Extract the components
trend = result.trend
seasonal = result.seasonal
residual = result.resid


adf_test = adfuller(residual.dropna())
print('ADF Statistic:', adf_test[0])
print('p-value:', adf_test[1])

# Print the results for clarity
print(f'ADF Statistic: {adf_test[0]}')
print(f'p-value: {adf_test[1]}')

# Apply differencing if needed
if adf_test[1] > 0.05:
    residual_diff = residual.diff().dropna()
else:
    residual_diff = residual.dropna()

# Visualize the residuals after differencing
plt.figure(figsize=(16, 8))
plt.plot(residual_diff, marker='o', linestyle='-')
plt.title('Differenced Residuals')
plt.xlabel('Date')
plt.ylabel('Differenced Residuals')
plt.grid(True)
plt.show()
```

In the code above, I first extract the trend, seasonal, and residual components from the STL decomposition result. I then apply the ADF test to the residuals to check for stationarity. The test outputs the ADF Statistic and the p-value (adf_test[1]). If the p-value is greater than 0.05, it indicates that the residuals are non-stationary, and I apply differencing to the residuals using "residual.diff ().dropna ()". If the p-value is less than or equal to 0.05, the residuals are already stationary, and no differencing is needed. Once I have applied differencing to the residuals, if necessary, I visualize the differenced residuals to confirm that the series is now stationary.

III.5.3.5 Analysis of testing results using ADF and differencing

The ADF test results indicate a strong rejection of the null hypothesis that the residuals have a unit root and are non-stationary. The ADF Statistic is -5.5583, which is significantly lower than the critical values for common significance levels (for 1%; -3.43) [29]. The p-value is extremely low (1.56e-06), well below the 0.05 threshold, confirming that the residuals are stationary.

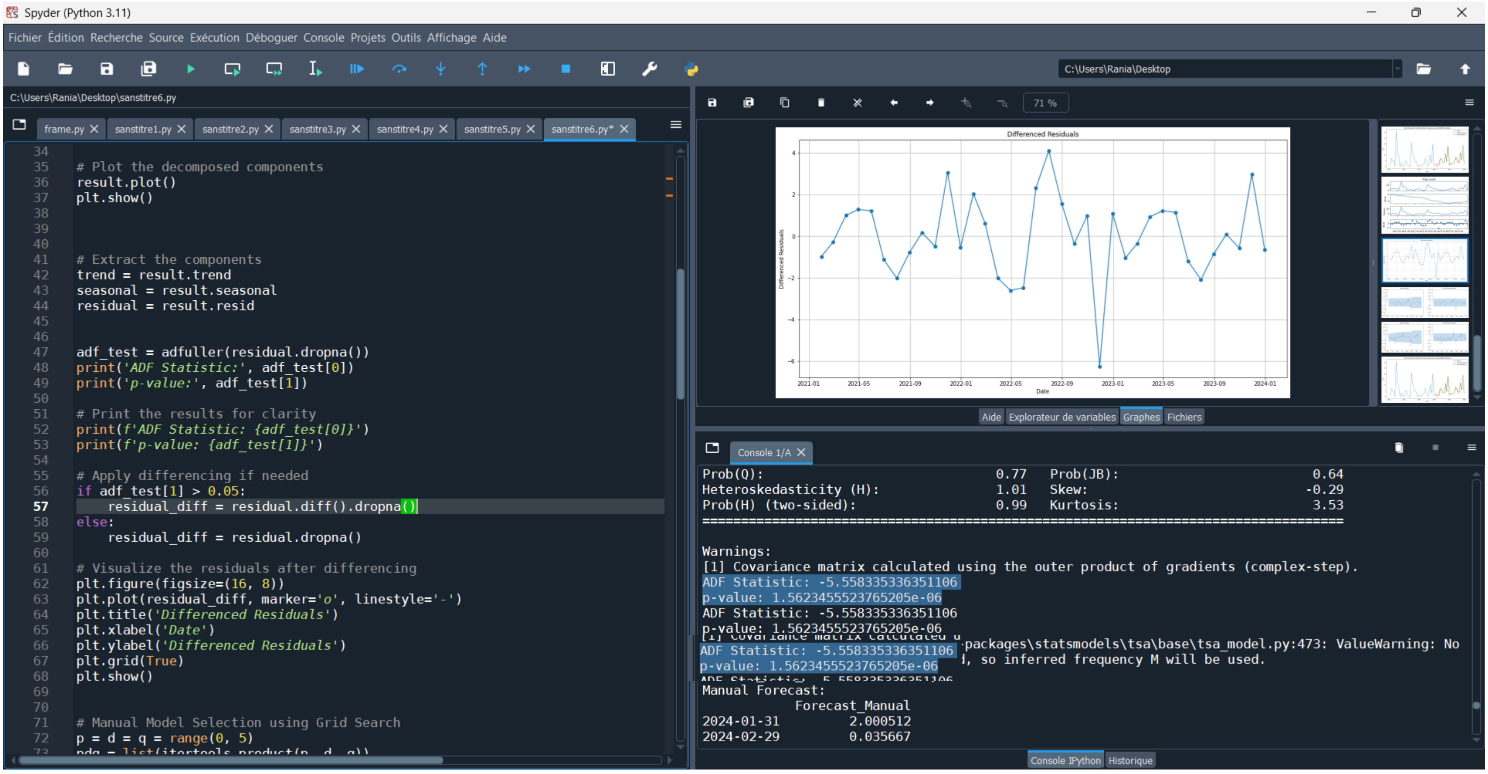


Figure III-16 ADF testing results

This line graph (Figure III-17) displays the differenced residuals of bait consumption data from January 2021 to January 2024.

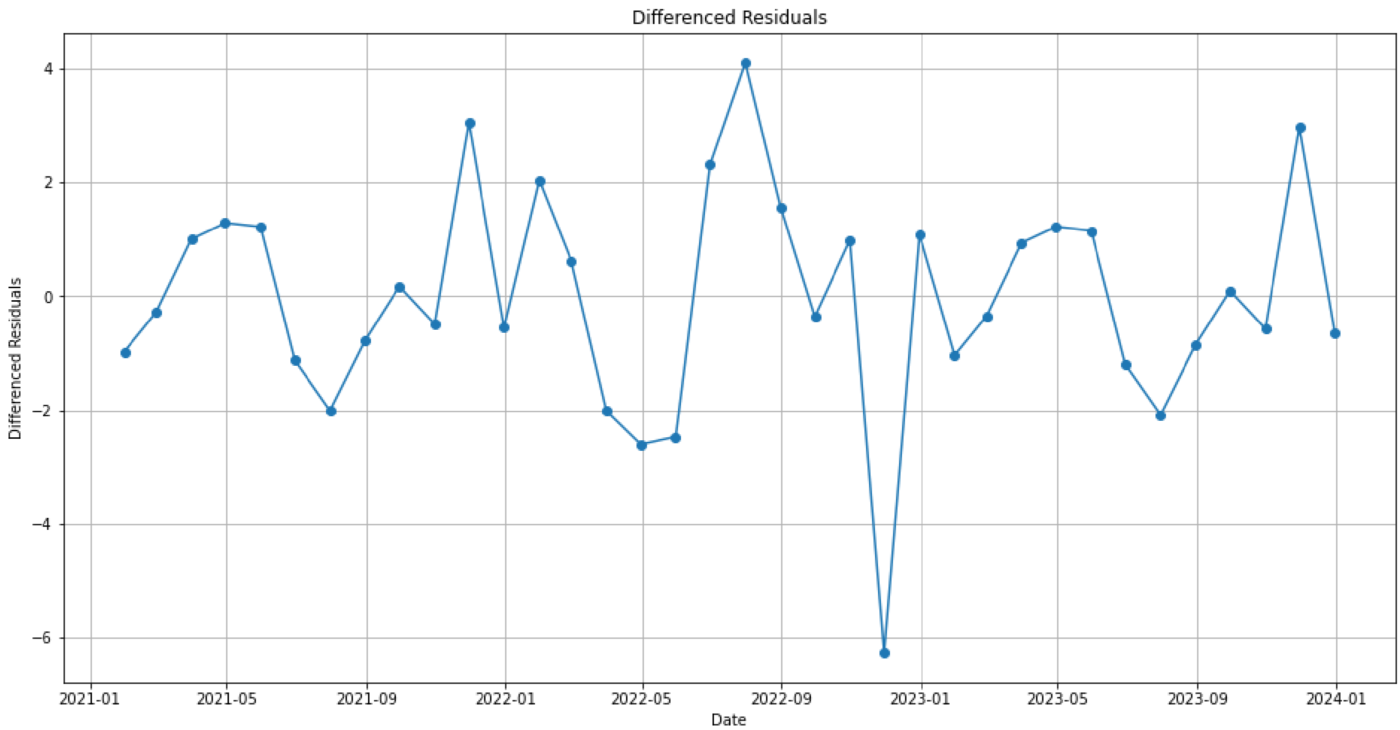


Figure III-17 Differenced Residuals line graph

The amplitude of the residuals' fluctuations appears relatively consistent over the observed period, further suggesting stationarity. This stability indicates that the series is now suitable for further time series modeling and forecasting.

III.5.3.6 Manual model selection using Grid Search

To find the best ARIMA model for a time series, I conducted a systematic search across various combinations of ARIMA parameters (p, d, and q). In a loop, I tested different sets of these parameters. Then, I chose the one with the lowest Akaike Information Criterion (AIC) to ensure that the chosen model neither oversimplifies nor overcomplicates the underlying patterns in the data. The following code snippet illustrates this manual model selection process using a grid search technique.

```python
# Manual Model Selection using Grid Search
p = d = q = range(0, 5) # Define the range of values for AR (p), differencing (d), and MA (q) components from 0 to 5
pdq = list(itertools.product(p, d, q)) # Generates all combinations
# Initialize Variables to Track the Best Model

best_aic_manual = np.inf # Stores the lowest AIC value found
best_order_manual = None # Stores the (p, d, q) order with the lowest AIC
best_mdl_manual = None # Stores the best ARIMA model found

for param in pdq: # Iterates over all combinations of (p, d, q)
    try:
        tmp_mdl = sm.tsa.ARIMA(residual_diff, order=param).fit() # Fits an ARIMA model for each combination
        tmp_aic = tmp_mdl.aic # Calculates the AIC for each model
        if tmp_aic < best_aic_manual:
            best_aic_manual = tmp_aic
            best_order_manual = param
            best_mdl_manual = tmp_mdl # Updates the best model if the current model’s AIC is lower than the previous best
    except Exception as e:
        print(f"Error fitting ARIMA{param}: {e}")
        continue #Ignore errors if a fitting model got a problem

print('Best Manual ARIMA order:', best_order_manual)
print('Best Manual AIC:', best_aic_manual)
print(best_mdl_manual.summary())
```

Figure III-18 Manual model selection using Grid Search

The result of the program are presented in the figure below

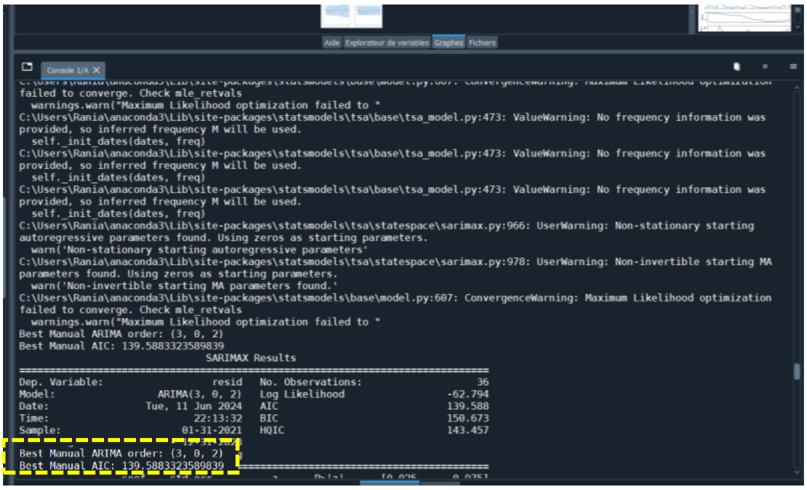


Figure III-19 AIC results for the best ARIMA model

Now I will use the automated ARIMA (auto_arima) and compare the two methods to get the most efficient one.

III.5.3.7 Automated model selection program

The auto_arima function automates the process of selecting the best ARIMA model for time series data. It begins by defining the parameter ranges for AR (p), differencing (d), and MA (q). Using a

```python
# Automated Model Selection using auto_arima
auto_model = auto_arima(residual_diff, start_p=0, start_q=0,
                        max_p=5, max_q=5, seasonal=False,
                        d=1, trace=True, error_action='ignore',
                        suppress_warnings=True, stepwise=False)

best_order_auto = auto_model.order
print('Best Auto ARIMA order:', best_order_auto)
print(auto_model.summary())
```

Figure III-20 Automatic ARIMA code

stepwise search algorithm, the function starts with a simple ARIMA model and iteratively adds or removes parameters to improve model fit. It evaluates each model based on the Akaike Information Criterion (AIC), balancing model complexity and goodness of fit. If the data is not stationary, auto_arima applies differencing automatically. The function includes built-in diagnostics to ensure model adequacy, handling errors gracefully during the search. Ultimately, it identifies the best (p, d, q) combination that minimizes AIC and outputs a summary of the best ARIMA model, including detailed diagnostics. The following code snippet (Figure III-20) illustrates this automated model selection process:

The result of the program are presented in the figure III-21 :

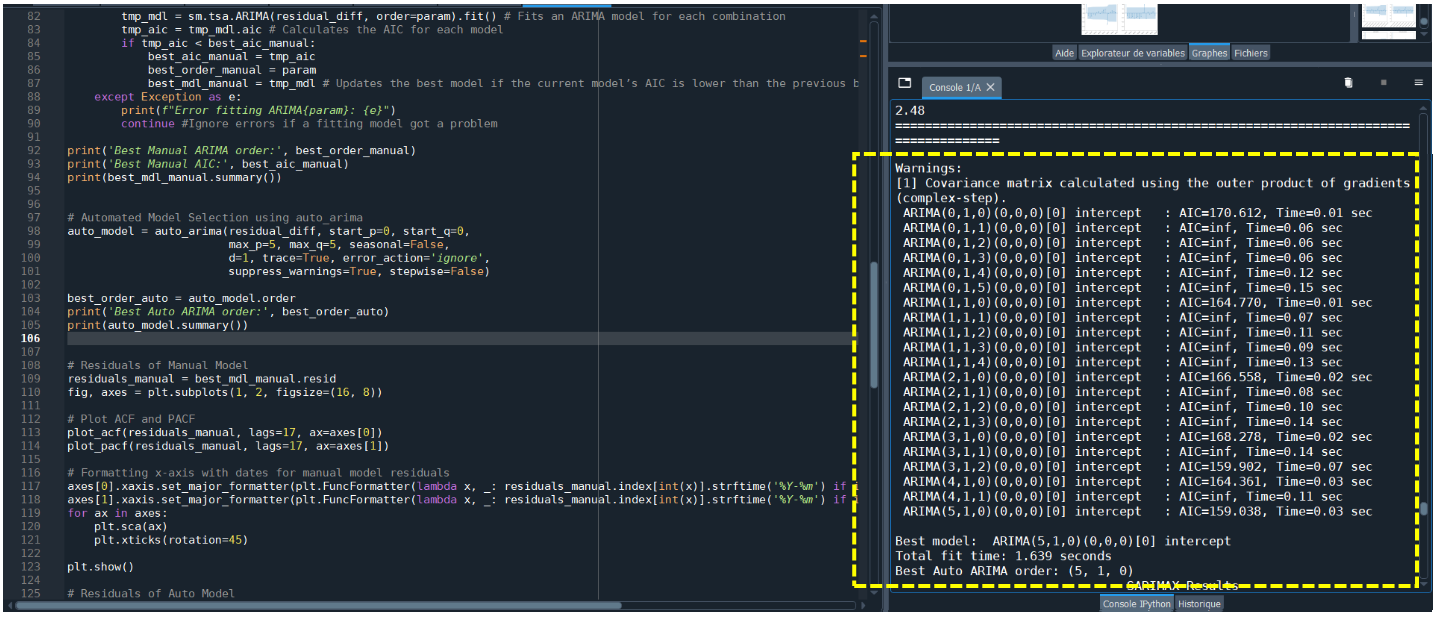


Figure III-21 Results of the automatic ARIMA application

III.5.3.8 Analyzing the residuals of manual and auto ARIMA’s model using ACF

To assess the adequacy of the fitted ARIMA models, I analyze the residuals of both the manually selected and automatically selected models. Plotting the Autocorrelation Function (ACF) of the residuals helps identify any remaining autocorrelation, which would indicate that the model has not fully captured the data's structure. In the following code (Figure III-22), I generate ACF plots for the residuals of both models:

```python
# Residuals of Manual Model
residuals_manual = best_mdl_manual.resid
fig, ax = plt.subplots(1, 1, figsize=(16, 8))

# Plot ACF for Manual Model Residuals
plot_acf(residuals_manual, lags=17, ax=ax)

# Formatting x-axis with dates for manual model residuals
ax.xaxis.set_major_formatter(plt.FuncFormatter(lambda x, _: residuals_manual.index[int(x)].strftime('%Y-%m') if int(x) < len(residuals_manual.index) else ''))
plt.xticks(rotation=45)
plt.show()

# Residuals of Auto Model
residuals_auto = auto_model.resid()
fig, ax = plt.subplots(1, 1, figsize=(16, 8))

# Plot ACF for Auto Model Residuals
plot_acf(residuals_auto, lags=17, ax=ax)

# Formatting x-axis with dates for auto model residuals
ax.xaxis.set_major_formatter(plt.FuncFormatter(lambda x, _: residuals_auto.index[int(x)].strftime('%Y-%m') if int(x) < len(residuals_auto.index) else ''))
plt.xticks(rotation=45)
plt.show()
```

Figure III-22 ACF plotting code for automatic and manual ARIMA

After generating these plots, I can proceed to discuss the results, comparing the performance of the two models in terms of how well they have captured the underlying structure of the time series data and whether any significant autocorrelation remains in their residuals.

III.5.3.9 Comparison between the automatic and manual ARIMA models

This section presents a comparative analysis of the best ARIMA models selected through both automatic and manual processes. The table III-8 summarizes ARIMA's Order, AIC and BIC for each approach.

Table III-8 ARIMA's Order, AIC and BIC for Auto and Manual ARIMA models

Model	ARIMA Order	AIC	BIC
Best Auto ARIMA	(5, 1, 0)	159,0	169,9
Best Manual ARIMA	(3, 0, 2)	139,6	150,7

The lower AIC and BIC values for the manual ARIMA model indicate its superior performance compared to the automatically selected model.

The slight differences in the residual patterns might hint that the manual model has slightly better performance given the lower AIC and BIC values previously discussed. Below figure III-28 and figure III-29 are the ACF plots of the residuals for both models.

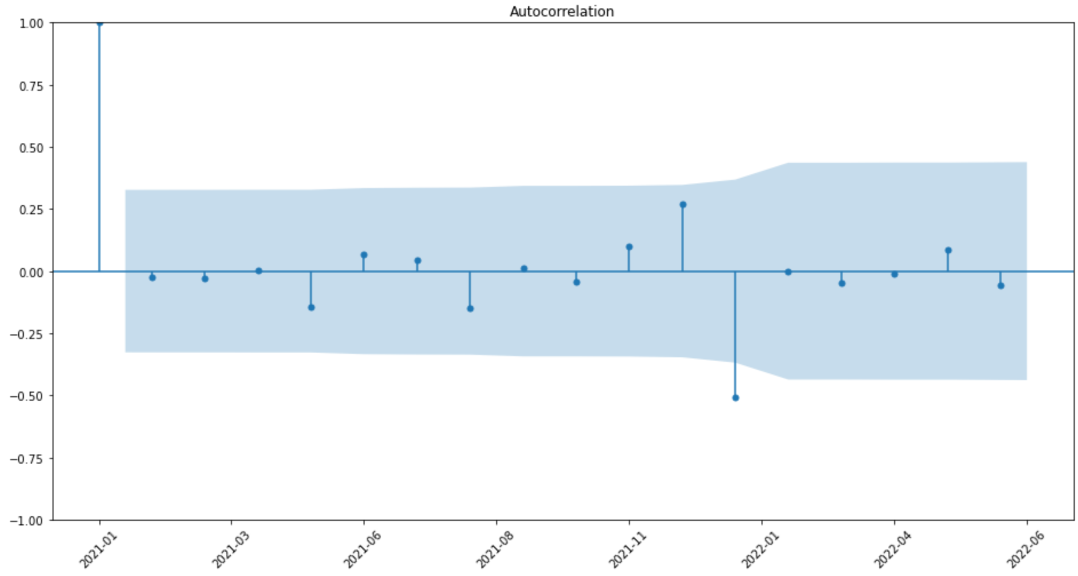


Figure III-23 Autocorrelation plot for the manual ARIMA model

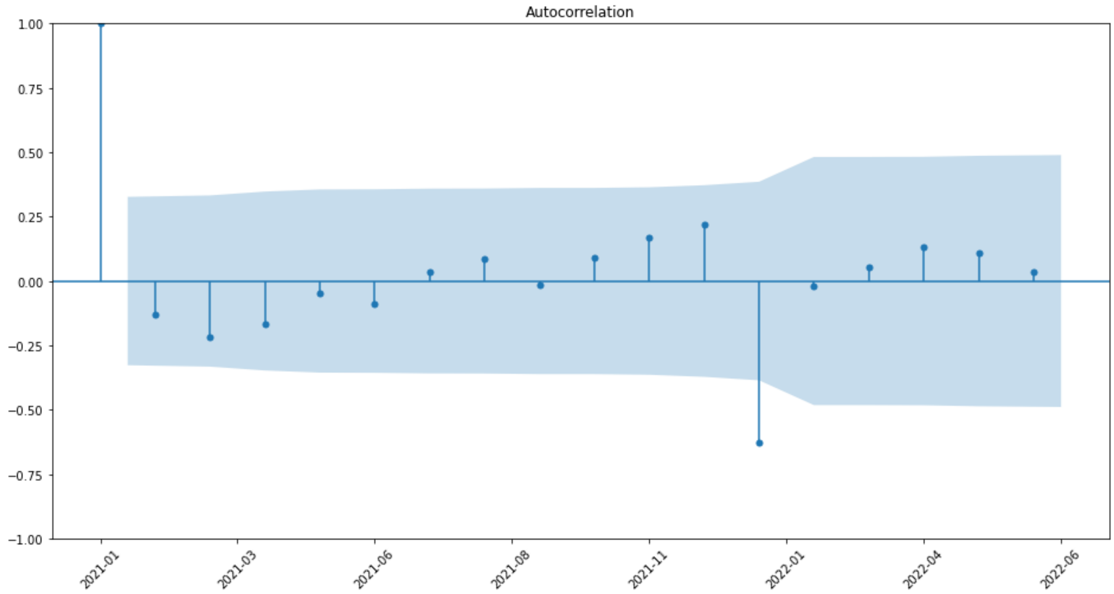


Figure III-24 Autocorrelation plot for the Automatic ARIMA model

These plots indicate that both models have effectively captured the underlying patterns in the time series data, because most of the autocorrelations fall within the confidence intervals

The comparison between the manual and auto ARIMA models highlights the importance of evaluating residuals through ACF plots to ensure that models do not leave significant autocorrelation unaddressed. Both models show promise, but the manual model's slightly better performance metrics (AIC and BIC) and similar residual patterns suggest it is the more robust option for forecasting. For this reason, we will adopt him in our next step for the forecasting of residuals.

III.5.3.10 Forecasting program

The forecasting procedure involves predicting each component of the time series separately: the residual, trend, and seasonal components. The following code snippet demonstrates the residual, trend and seasonal forecasting using ARIMA, Exponential smoothing, and repeating seasonal pattern respectively:

```python
# Forecasting with the Manual Model
residual_forecast_manual = best_mdl_manual.predict(start=len(residual_diff), end=len(residual_diff)+23)


# Forecast the trend component using Exponential Smoothing
trend_model = sm.tsa.ExponentialSmoothing(trend.dropna(), trend='add', seasonal=None).fit()
trend_forecast = trend_model.forecast(steps=24)

# Forecast the seasonal component by repeating the last year's seasonal pattern
seasonal_forecast = np.tile(seasonal[-12:], 2)  # Repeat the last year's seasonal pattern

# Combine the forecasts
combined_forecast_manual = trend_forecast + seasonal_forecast + residual_forecast_manual
```

Figure III-25 Forecasting the residual, trend, and seasonal components program

Following the forecasting process, the next step will be to deliver and discuss the results.

III.5.3.11 Forecasting Results and Risk Management Implications

In this section, we present the results of the forecast for trap consumption from January 2024 to December 2025. The forecasted values have been derived using a combination of the trend, seasonal, and residual components obtained by running the code in Appendix 9.

Table III-9 Forecasted numbers of bait consumption for the next two years

Date	Consumed baits	Date	Consumed baits
2024-01	2	2025-01	2
2024-02	0	2025-02	2
2024-03	1	2025-03	3
2024-04	1	2025-04	3
2024-05	6	2025-05	7
2024-06	6	2025-06	6
2024-07	4	2025-07	3
2024-08	3	2025-08	3
2024-09	11	2025-09	11
2024-10	4	2025-10	5

2024-11	17	2025-11	19
2024-12	1	2025-12	2

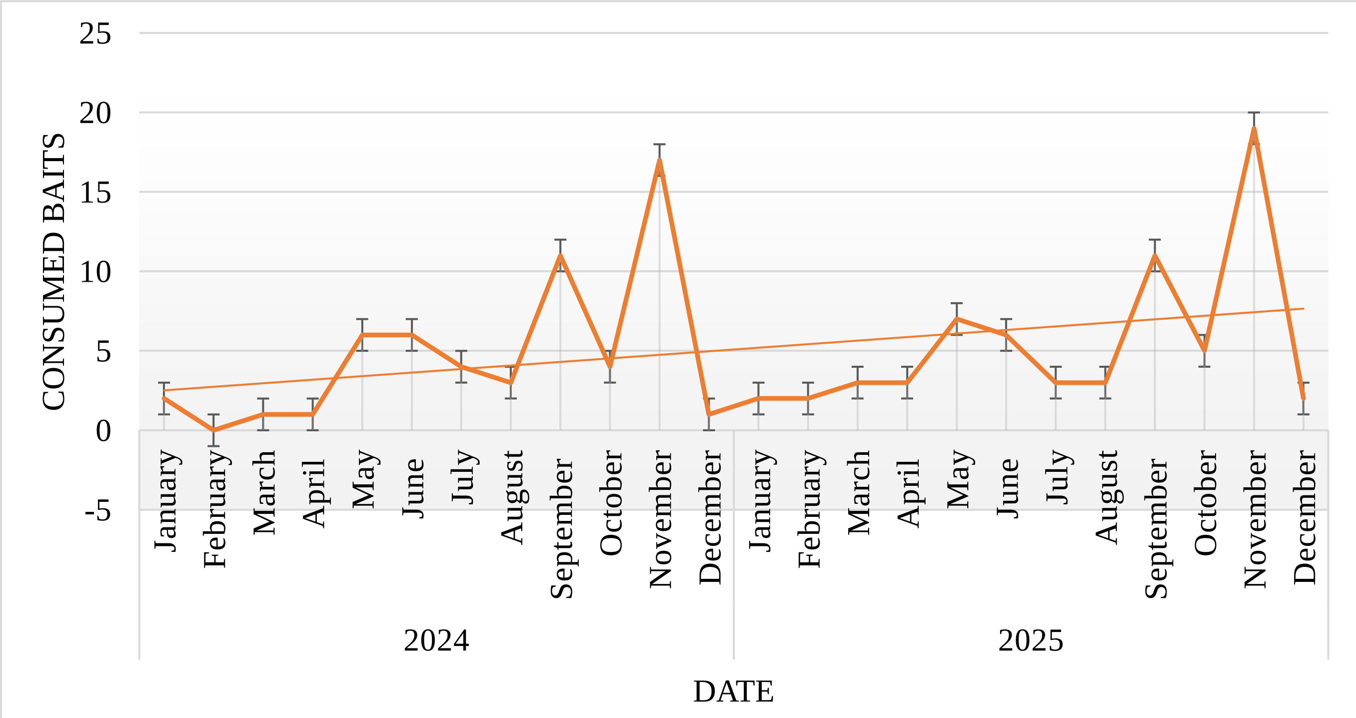


Figure III-26 Final forecast combining the Trend exponential smoothing, Seasonal, and ARIMA residuals

The values represent the expected activity levels of pests, which are critical for planning pest control measures. The forecast indicates a clear seasonal pattern, with lower bait consumption during the winter months (January, February, and December) due to reduced pest activity in colder weather. In contrast, there is a gradual increase in bait consumption in spring (March, April, May) as the weather warms up, leading to higher pest activity, particularly in May. The summer months (June, July, and August) maintain a moderate level of bait consumption, with a slight dip in August. The peak in bait consumption is observed in autumn (September, October, November), with September and November showing significant spikes, indicating critical periods for pest control measures.

Year-to-year consistency is evident, with similar patterns of peaks and troughs in both 2024 and 2025. For instance, September and November consistently show higher bait consumption in both years, with November 2025 (19 baits) being slightly higher than November 2024 (17 baits), indicating a potential increase in pest activity that may need more intensive control measures.

The predicted values align with historical patterns, showing seasonal peaks that reflect past consumption trends. The forecast effectively captures these cyclical patterns, demonstrating the robustness of the manual ARIMA model.

One of the standout features of this model is its dynamic nature. It is not limited to forecasting rodent trap consumption; it can be adapted to incorporate data from any other pest. This versatility ensures that the model remains relevant and useful across various scenarios, providing reliable forecasts regardless of the type of pest data integrated.

Based on these findings, I suggest that ECCBC allocate resources by intensifying pest control measures during high activity periods, especially in May, September, and November, while focusing on preventive measures and maintenance during low activity periods in the winter months.

III.5.4 About the prediction model

One of the standout features of this model is its dynamic nature. It is not limited to forecasting rodent trap consumption; it can be adapted to incorporate data from any other type of pest. This versatility ensures that the model remains relevant and useful across various scenarios, providing reliable forecasts regardless of the type of pest data integrated. By incorporating more data, the accuracy of the forecasts improves, allowing for more precise and effective pest control measures.

Despite its strengths, the prediction model has some limitations. The data is limited to monthly intervals; having daily data would provide more detailed and accurate forecasts. Additionally, while the model gives valuable insights, it should be continuously validated against actual data to ensure its reliability. However, its adaptability makes it a powerful tool in the pest management strategy. The more data fed into the model, the more accurate the forecasts will become, allowing for more precise and effective pest control measures.

This approach allows us to allocate resources more effectively, reinforcing preventive actions and minimizing pesticide as a result, we will promote a more sustainable pest management strategy.

III.6 Conclusion

In this chapter, I focused on enhancing ECCBC’s pest management system by implementing the action plan outlined in Chapter II. The initial step involved conducting a thorough pest analysis, which identified the primary pests and their environmental influences. This analysis facilitated the identification of both internal and external environmental factors affecting pest behavior. By evaluating the facility's zones using criteria such as attractions and vulnerability, I was able to pinpoint the most influential areas.

The pest analysis highlighted the limitations of the current strategies and underscored the potential for integrating new technologies. However, the primary issue identified was the absence of a cohesive pest management system. To address these issues, I analyzed the existing data, using rodent trap consumption as a case study. This analysis revealed valuable insights into pest activity patterns and resource utilization.

Subsequently, I designed a predictive model incorporating STL, ARIMA, and Exponential Smoothing techniques. These models provided accurate forecasts of pest activity, enabling us to allocate resources more effectively, reinforcing preventive actions.

Chapter IV

Risk Evaluation Design and $IPM_{1.0}$ interface

IV.1 Introduction

In this chapter, I will work on the implementation of the IPM system using the theoretical foundations (figure I-5). This system operates as a continuous loop, starting with the monitoring of pest activity data, which I worked on in the previous chapter. This data is evaluated in order to determine the risk level. According to [30], and [31] , each food business should assess its specific situation to determine the risk posed by pests. Therefore, I decided to create a dynamic risk evaluation algorithm inspired from the standards methods. Based on the risk level, we can decide what measure should be implemented following the theoretical foundations.

To improve the efficiency and responsiveness of the pest management efforts, I have developed a specialized interface that incorporates the IPM features, designed using Visual Basic for Applications (VBA). It facilitates the practical application of the IPM by providing a user-friendly platform for data input, risk calculation, and reporting.

By leveraging this automated approach, we ensure a proactive and effective pest management strategy that adapts to varying risk levels, ultimately enhancing food safety and operational efficiency.

IV.2 Risk evaluation algorithm design

After a long study of the pest's behaviors, their characteristics and their attractions [32], I developed a risk assessment algorithm designed to establish precise threshold levels for pest management. This algorithm is based on several parameters influencing the pest related risks. It considers the following parameters:

(i) Trap Counts: The number of pests caught in traps is a direct indicator of population levels
(ii) Activity Signs: Observing signs reveals on presence and movement patterns of pests
(iii) Current Sanitary condition is an attracting or deterring factor
(iv) Season influences pest behavior (changings).
(v) Zone as explained previously in III.2.3.2 different facility areas have varying levels of pest attraction and vulnerability

Since the risk score in this case is not influenced by one parameter, a simple matrix approach like 2x2 or 3x3 was inadequate for our needs. Instead, I opted to apply the Analytic Hierarchy Process (AHP) to determine the relative weight of each parameter. This choice is not only for the complexity of the parameters but also enhances the precision of the risk assessment by incorporating expert judgment. Using AHP, I calculated the weight each parameter to the overall risk score. Finally, I defined the limits of the risk levels based on a structured methodology.

The subsequent sections will delve into the detail of each step.

IV.2.1 Data input

The data input section outlines the various parameters and indicators that feed into the risk assessment algorithm. These inputs are critical for accurately predicting and managing pest infestations.

IV.2.1.1 Trap Counts

Trap counts are a critical component of the risk assessment algorithm. It was actually the hardest to design, given the critical nature of food safety and the different behavior of pests in different areas. Therefore, I have to mention that we need to continuous review and adjust the trap count limits to ensure they remain effective. We chose the current limits to provide a reasonable framework based on historical data and professional experience. These limits are specific to ECCBC and were determined for its specific case, considering input from an experienced pest control expert and the opinions of contractors.

IV.2.1.1.1 Rodents trap counts limits

According to the professionals' experience of ECCBC, the data history of the subcontractor and the understanding of the behavior of rodents, the table IV-1 sets the limits.

Table IV-1 Rodent trap count evaluation matrix

Rodents trap count (Rc)	Level	Explanation
Rc < 4	1	This level indicates a low level of rodent activity. While occasional rodents may be present, the situation is manageable and does not pose a significant damage.
7 < Rc < 4	2	This intermediate level signifies a moderate level of rodent activity. It suggests that the rodent population is increasing and may soon pose a more significant damage if not addressed promptly.
Rc > 7	3	This level represents a high level of rodent population.

IV.2.1.1.2 Insect trap counts limits

According to the professionals' experience at ECCBC, the historical data from the subcontractor, and a thorough understanding of the behavior of flies and mosquitoes [32], the tables IV-2 & 3 sets the limits.

Table IV-2 Flies count evaluation matrix

Flies trap count (Fc)	**Level**	**Explanation**
Fc< 30	1	This level indicates a low level of fly activity. Occasional flies may be present, but the situation is manageable and does not pose a significant damage.
$30 \leq Fc \leq 70$	2	This intermediate level signifies a moderate level of fly activity. It suggests that the fly population is increasing and may soon pose a more significant damage.
Fc > 70	3	This level represents a high level of fly activity, indicating a severe damage.

Table IV-3 Mosquitos count evaluation matrix

Mosquitos count (Mc)	**Level**	**Explanation**
Mc < 15	1	This level indicates a low level of mosquito activity. Occasional mosquitoes may be present, but the situation is manageable and does not pose a significant risk to food safety.
$15 \leq Mc \leq 35$	2	This intermediate level signifies a moderate level of mosquito activity. It suggests that the mosquito population is increasing and may soon pose a more significant risk if not addressed promptly.
Mc > 35	3	This level represents a high level of mosquito activity, indicating a severe infestation. Immediate and robust action is required to mitigate the risk to food safety.

These limits for fly and mosquito trap counts help systematically assess and address pest population within the facility.

IV.2.1.2 Season

The Season parameter in the risk assessment algorithm is vital for predicting infestation risk level. This parameter allows us to incorporate the effects of environmental conditions, such as temperature and photoperiod, in an integrated manner. Although the relationship with temperature is weak as we have seen previously, it is still significant and impacts the reproductive cycles and behavioral changes of pests, including flies, mosquitoes [33], and rodents [34].

By considering the reproductive cycles and behavioral changes of pests, the Season Parameter enhances the accuracy of risk assessment for pest infestations.

To evaluate these criteria, we define the following matrix (table IV-4)

Table IV-4 : Season scoring levels

Season	**Level**
Winter	1
Autumn	2
Summer / Spring	3

The season scoring levels in table -IV4 provide a structured approach to quantifying the impact of different seasons on pest risk levels. Each season is assigned a score that reflects its influence on pest activity and infestation potential.

Level 1: During winter, lower temperatures and shorter daylight periods typically result in reduced pest activity and reproductive cycles. Consequently, the risk of infestations is lower, which is reflected in the scoring level.

Level 2: In autumn, moderate temperatures and changing photoperiods lead to a moderate level of pest activity. The risk of infestations begins to increase as pests prepare for the winter months, warranting a higher score compared to winter.

Level 3: warmer temperatures and longer daylight periods characterize summer and spring, which boost the reproductive cycles and activity levels of pests. This period sees the highest risk of infestations, as reflected in the highest scoring level.

Overall, the season parameter enables the algorithm to account for seasonal variations in pest behavior and activity.

IV.2.1.3 Activity sign

Every pest leaves behind distinct traces, acting as clear indicators of their presence in an environment. This was the main reason why I chose this parameter as a key component of the risk level evaluation. It is crucial since it shows the severity of the situation.

To categorize the severity of pest activity, we use the following activity sign levels (table IV-5);

Table IV-5 Activity sign evaluation matrix

Activity sign	Level
High	3
Moderate	2
Low	1

There are two primary methods to determine these levels:

- Utilize your expertise and experience to evaluate the severity of the pest activity signs.

Or use the provided checklists to identify and record pest activity signs, then calculate the percentage of yes responses for each pest category. By a standard practice You can get the activity sign level (table IV-6).

Table IV-6 Activity sign level with its respective compliance percentage

Activity sign	Level	Compliance percentage
High	3	75% - 100%
Moderate	2	50% - 74.9%
Low	1	0% - 49.9%

IV.2.1.3.1 Rodents checklists

The rodents' checklists include the indicators identified in III.2.4.1 for both rats and mice, as seen in table IV-7.

Table IV-7 Checklist's template related to rodents

Rats Activity Signs				
N°	**Questions**	**Result**	**Deviation**	**Observation**
1	Have you found dark brown, spindle-shaped droppings resembling rice grains?			
2	Are there grease and dirt marks on surfaces?			
3	Can you see bite marks on wires, cables, or objects stored in the attic?			
4	Are there rat holes or burrow systems around the property?			
5	Can you find nests made of shredded materials like attic insulation or cardboard?			
6	Do you observe rat footprints and tail marks in dusty and rarely used areas?			
7	Have you spotted burrow systems or holes around the property?			

Mice Activity Signs				
N°	**Questions**	**Result**	**Deviations**	**Observations**
1	Are there 50 to 80 small dark droppings scattered randomly per night?			
2	Do you see dark marks around holes or corners caused by mice rubbing their bodies?			
3	Have you found small mounds composed of body grease, dirt, and urine?			
4	Do you hear scratching noises at night between walls, under floors?			
5	Are nests found in places like attics, hollow walls, or behind appliances?			
6	Have you seen live or dead mice during the day, indicating a significant infestation?			

Commun Signs				
N°	Questions	Result	Deviation	Observation
1	Do you hear scratching noises between walls, under floors, especially at night?			
2	Have you inspected attics, hollow walls, and behind appliances for nests made of easily shredded materials?			
3	Have you sprinkled flour or talcum powder in unused areas and checked the next day for fresh tracks?			
4	Do you notice a strong ammonia smell, particularly in areas where rodents might be active?			

Activity sign || Rats	**0%**
Activity sign || Mice	**0%**

IV.2.1.3.2 Insects

The insects' checklists of includes the indicators identified in III.2.4.2 for both flies and mosquitoes, as seen in table IV-8.

Table IV-8 Checklist's template related to insects

Flies activity signs				
N°	Questions	Result	Deviation	Observation
1	Are flies frequently visible around your premises?			
2	Have you found small dark spots, the size of a pinhead, on light fixtures or upper walls, which could be fly droppings?			
3	Have you noticed flies or larval (maggot) activity in or around the bottling areas, particularly under equipment or in hard-to-clean corners?			
4	Do you notice any unusual odors that might suggest the presence of decaying matter, such as a dead rodent, which could attract flies?			

5	Has there been warm weather that might accelerate fly lifecycles, potentially turning a minor issue into a major infestation?			
6	Are adult flies appearing to multiply in number within your premises?			
7	Do you see fly feces, resembling clusters of tiny black dots, in areas where flies might be feeding or nesting?			

Mosquitoes activity signs				
N°	**Questions**	**Result**	**Deviation**	**Observation**
1	Have you observed adult mosquitoes during the day or evening?			
2	Have you seen mosquitoes resting on walls, ceilings, or other surfaces?			
3	Have you observed mosquito larvae wriggling in stagnant water?			
4	Have there been reports of mosquito bites from staff or visitors?			
5	Are there complaints about itching or red welts, typically on exposed skin areas?			
6	Have you captured mosquitoes in light traps or other monitoring devices?			

Activity sign || Flies	**0%**
Activity sign || Mosquitoes	**0%**

For all pests, each checklist item should be marked as either Yes (1), No (0), or Not Applicable (NA). And then calculate the compliance level (Eq IV-1)

$$Compliance\ level = \left(\frac{Observed\ number\ of\ Yes}{Totale\ applicable\ questions}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (IV\text{-}1)$$

IV.2.1.4 Current sanitary condition

The current sanitary condition is a crucial parameter in the risk assessment algorithm, as it significantly influences the likelihood of pest infestations.

The assessment of the current sanitary condition (CSS) is determined by either (i) the professional judgment of the evaluator or (ii) the internal Good Manufacturing Practices (GMP) assessment checklist provided by ECCBC, ensuring a comprehensive evaluation that aligns with industry standards.

Following this assessment, we can determine level of sanitation through the CSS evaluation matrix, and assign numerical values to the different levels (table IV-9)

Table IV-9 CSS evaluation matrix

Current Sanitary Condition	Level	Explanation
Good	1	High level of cleanliness
Moderate	2	Intermediate level of sanitation
Low	3	Poor level of cleanliness

IV.2.1.5 Zone

To assess the "zone" factor in the context of pest risk assessment, I will adopt the same scoring system performed previously (III.2.3.2).

IV.2.2 Weights calculation

In this section, I will calculate the weights of the parameters using the AHP method. It is a structured technique for organizing and analyzing complex decisions, which is beneficial for risk assessment as it allows for the quantification of subjective judgments and ensures logical consistency in comparisons [35]. The AHP method is a process of multiple steps: (i) develop the hierarchy, (ii) Pairwise comparisons, (iii) Priority Vector Calculation (the weights) Calculation, (iv) Check Consistency, (v) Fix the weight.

IV.2.2.1 Hierarchical structure

I created a hierarchical structure (figure IV-1) starting with the overall goal at the top, which is determining the risk level, followed by criteria and finally the alternatives at the bottom.

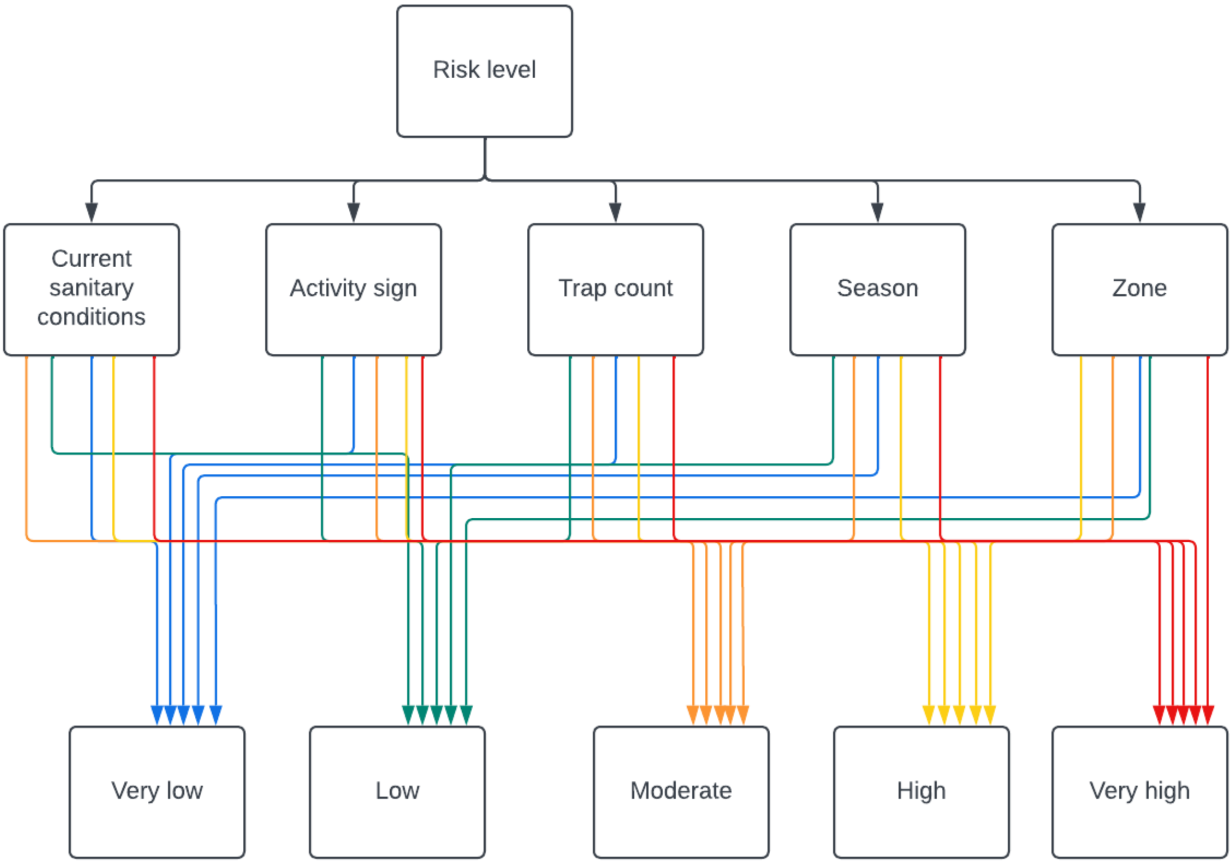


Figure IV-1 Graphic representation of the hierarchical structure

IV.2.2.2 Pairwise comparison matrix

First, we construct a pairwise comparison matrix where each criterion is compared against every other criterion based on their relative importance. The importance scale used ranges from 1 to 5, as followed:

1: Equal importance;

2: Slight importance of one over another;

3: Moderate importance of one over another;

4: Strong importance of one over another;

5: Very strong or essential importance of one over another.

To facilitate the reading of the matrixes, I will use the symbols :

- AS for Activity sign,
- TC for trap count,
- S for season,

- Z for zone,
- CSS for current sanitary condition.

$$
\begin{array}{c} \\ A = \end{array}
\begin{array}{c} \text{AS} \quad \text{TC} \quad \text{S} \quad \text{Z} \quad \text{CSS} \\
\begin{bmatrix} 1 & 2 & 3 & 4 & 3 \\ 1/2 & 1 & 2 & 3 & 4 \\ 1/3 & 1/2 & 1 & 2 & 2 \\ 1/4 & 1/3 & 1/2 & 1 & 2 \\ 1/3 & 1/4 & 1/2 & 1/2 & 1 \end{bmatrix} \end{array}
\begin{array}{c} \text{AS} \\ \text{TC} \\ \text{S} \\ \text{Z} \\ \text{CSS} \end{array}
$$

This matrix serves as the foundation for further calculations to determine the weights of each parameter.

IV.2.2.3 Column Sums Calculation

Next, we calculate the sum of each column in the pairwise comparison matrix to normalize the matrix.

	AS	TC	S	Z	CS
AS	1	2	3	4	3
TC	1/2	1	2	3	4
S	1/3	1/2	1	2	2
Z	1/4	1/3	1/2	1	2
CSS	1/3	1/4	1/2	1/2	1
Total	2.4	4.1	7	10.5	12

These sums provide the basis for transforming the original pairwise comparisons into a normalized form, ensuring that each criterion is proportionally represented.

IV.2.2.4 Normalizing the Matrix

After that, we normalize the matrix; each element in the pairwise comparison matrix is divided by the sum of its respective column.

$$\text{Normalized Matrix}_{ij} = \frac{\text{Original Matrix}_{ij}}{Sum\ of\ Column_j} \quad \text{..........(IV-2)}$$

NA :

$$
A_{norm} = \begin{array}{c} \text{AS} \quad \text{TC} \quad \text{S} \quad \text{Z} \quad \text{CSS} \\
\begin{bmatrix} \mathbf{0.41} & \mathbf{0.49} & \mathbf{0.43} & \mathbf{0.38} & \mathbf{0.25} \\ \mathbf{0.20} & \mathbf{0.24} & \mathbf{0.28} & \mathbf{0.28} & \mathbf{0.33} \\ \mathbf{0.14} & \mathbf{0.12} & \mathbf{0.14} & \mathbf{0.19} & \mathbf{0.16} \\ \mathbf{0.10} & \mathbf{0.08} & \mathbf{0.07} & \mathbf{0.09} & \mathbf{0.16} \\ \mathbf{0.13} & \mathbf{0.06} & \mathbf{0.07} & \mathbf{0.05} & \mathbf{0.08} \end{bmatrix} \end{array}
\begin{array}{c} \text{AS} \\ \text{TC} \\ \text{S} \\ \text{Z} \\ \text{CSS} \end{array}
$$

This step ensures that the comparisons are proportional and can be accurately used to determine the priority vector.

IV.2.2.5 Priority Vector Calculation

The priority vector, representing the relative weights of the criteria, is calculated by averaging each row in the normalized matrix (IV-3)

$$Priority\ Vector_i = \frac{\sum_{i=1}^{5} Normalized\ Matrix_{ij}}{5} \text{.............. (IV-3)}$$

NA:

$$Priority\ Vector_i = \begin{bmatrix} (0.4136 + 0.4890 + 0.4286 + 0.3809 + 0.25)/5 \\ (0.2068 + 0.2445 + 0.2857 + 0.2857 + 0.3333)/5 \\ (0.1379 + 0.1223 + 0.1429 + 0.1905 + 0.1667)/5 \\ (0.10 + 0.08 + 0.07 + 0.09 + 0.16)/5 \\ (0.13 + 0.06 + 0.07 + 0.05 + 0.08)/5 \end{bmatrix} = \begin{bmatrix} \mathbf{0.40} \\ \mathbf{0.27} \\ \mathbf{0.15} \\ \mathbf{0.10} \\ \mathbf{0.08} \end{bmatrix}$$

The priority vector indicates the relative importance of each criterion in the context of risk assessment. These weights are derived by averaging the normalized values across each row, reflecting the overall priority assigned to each parameter.

IV.2.2.6 Consistency Vector

We start by calculating the Weighted Sum Vector (WSV). It is obtained by multiplying the pairwise comparison matrix A by the priority vector w.

$$\text{WSV} = A \times w \text{..................(IV-4)}$$

NA:

$$\text{WSV} = \begin{bmatrix} \mathbf{0.4} \\ \mathbf{0.27} \\ \mathbf{0.15} \\ \mathbf{0.1} \\ \mathbf{0.08} \end{bmatrix} \times \begin{bmatrix} \mathbf{0.41} & \mathbf{0.49} & \mathbf{0.43} & \mathbf{0.38} & \mathbf{0.25} \\ \mathbf{0.20} & \mathbf{0.24} & \mathbf{0.28} & \mathbf{0.28} & \mathbf{0.33} \\ \mathbf{0.14} & \mathbf{0.12} & \mathbf{0.14} & \mathbf{0.19} & \mathbf{0.16} \\ \mathbf{0.10} & \mathbf{0.08} & \mathbf{0.07} & \mathbf{0.09} & \mathbf{0.16} \\ \mathbf{0.13} & \mathbf{0.06} & \mathbf{0.07} & \mathbf{0.05} & \mathbf{0.08} \end{bmatrix} = \begin{bmatrix} 2.02 \\ 5.23 \\ 0.80 \\ 0{,}55 \\ 0{,}44 \end{bmatrix}$$

Then we calculate λ as follow: $\lambda = \frac{\text{WSV}}{w}$ ....(IV-5)

AN:

$$\lambda = \begin{bmatrix} 5.15 \\ 1.42 \\ 5.23 \\ 5.33 \\ 5.48 \end{bmatrix}$$

IV.2.2.7 The average of the consistency vector

Calculate the average of the consistency vector, the formula is

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(A\times w)i}{wi} \text{……………….(IV-6)}$$

NA:

$$\boldsymbol{\lambda_{max}} = \frac{5.1565 + 5.2347 + 5.2386 + 5.3375 + 5.4838}{5} = 5.29$$

Now that we have λ_{max}, we can use it to calculate the Consistency Index (CI) and the Consistency Ratio (CR)

IV.2.2.8 Check for Consistency

To ensure the reliability of the comparisons, we calculate the Consistency Index (CI) and the Consistency Ratio (CR). These measures indicate whether the comparisons made are consistent and logical. The matrix is considered consistent if the CR is less than 0,1.

The calculation of the consistency index [36] is given by the following formula:

$$\boldsymbol{CI} = \frac{\lambda\, max - n}{n-1} \text{ ……………..(IV-7)}$$

Where CI is the consistency index and n is the number of evaluated criteria.

NA: $\boldsymbol{CI} = \frac{5,29-5}{5-1} = \frac{0,29}{4} = 0.072$

We evaluate the consistency of our judgments by calculating the consistency ratio (CR). This is done by dividing our consistency index (CI) by the random consistency index (RI). The values of the RI are available in the table below:

Table IV-10 Random consistency index values

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

We consider our comparison matrix to be consistent if the resulting consistency Ratio (CR) is less than 10 %.

$$CR = \frac{CI}{RI} \text{ ………… (IV-8)}$$

NA : CR= $\frac{0,072}{1,12}$ = 0.064 = **6,47%** < 10%

In this case, the CI is 0.072, and the RI is 1.12. The resulting CR of 6.47% is less than the commonly accepted threshold of 10%, suggesting that the judgments are consistent and the weights derived from the AHP are reliable.

IV.2.2.9 Criteria weights

Based on the calculations and consistency check using the Analytic Hierarchy Process (AHP), I have determined the weights for each criterion involved in the risk assessment. These weights reflect the relative importance of each criterion and will be used to calculate the risk score.

Table IV-11 The criteria's weight

Criteria	Sign	Trap count	Season	Zone	Current sanitary condition
Weight	40%	27%	15%	10%	0.08%

The table above summarizes the weights assigned to each criterion. These weights are the result of the AHP analysis, which involved pairwise comparisons, normalization, and consistency checking. The 'Sign' criterion, with the highest weight of 40%, is identified as the most critical factor in the risk assessment. 'Trap Count' follows with 27%, while 'Season', 'Zone', and 'Current Sanitary Condition' each contribute between 10% to 15% to the overall risk assessment.

Finally, we can say that the risk is calculated as follow:

$$Risk\ score = Trap\ count\ level\ \times 0.27\ + Sign\ level \times 0.40\ + Season\ level\ \times 0.15\ + Zone\ level \times 0.08\ + CSC\ level\ \times 0.10 \quad IV\text{-}9)$$

These calculated weights provide a structured and quantifiable basis for assessing the risk level.

IV.2.3 Classification of Risk Levels Based on Parameter Combinations

Since we are working with multiple parameters, each having several possible values, calculating all potential risk levels can be complex due to the 324 possible combinations. To streamline this process, we employed a Python program to compute all the possibilities. These results were then divided into equal intervals to classify the risk limits from very low to very high.

IV.2.3.1 Possible Values for Each Parameter

The table (IV-12) summarizes the possible values for each parameter used in the risk level calculation:

Table IV-12 Possible Values for Each Parameter

Parameter	Number of Possible Values	Values
Current Sanitary Condition	3	1 (Good), 2 (Moderate), 3 (Low)
Place	4	1, 2, 3, 4
Activity Sign	3	1 (High), 2 (Moderate), 3 (Low)
Trap Counts	3	1 (High), 2 (Moderate), 3 (Low)
Season	3	1(Winter), 2 (Autumn), 3 (Spring/Summer)

IV.2.1 Risk Evaluation Scale

I will evaluate the risk levels based on the calculated scores and assign each scenario a corresponding risk level.

IV.2.1.1 The program for risk evaluation scale

Given the complexity of determining risk levels from multiple parameters, we utilized a Python program to automate the calculation of all possible combinations. This program helps in efficiently categorizing risk levels based on the weighted sum of parameter values. By dividing the possible scores into equal intervals, we can classify risk levels from "Very Low" to "Very High.

```python
# Criteria values and their weights
criteria_values = {
    'CSC': [1, 2, 3],  # Good, Moderate, Low
    'Place': [0, 1, 2, 3, 4],  # 1: Least favorable, 4: Most favorable
    'Season': [1, 2, 3],  # Winter/Summer, Autumn, Spring
    'Likelihood': [1, 2, 3],  # Low, Moderate, High
    'Sign': [1, 2, 3]  # Low, Moderate, High
}

weights = {
    'CSC': 0.08,
    'Place': 0.1,
    'Season': 0.15,
    'Likelihood': 0.27,
    'Sign': 0.4
}

# Calculate the maximum and minimum possible scores
max_score = sum(max(values) * weights[key] for key, values in criteria_values.items())
min_score = sum(min(values) * weights[key] for key, values in criteria_values.items())

# Calculate the range and determine thresholds
range_size = (max_score - min_score) / 5
risk_thresholds = [min_score + i * range_size for i in range(6)]

# Print the risk level thresholds
risk_levels = ['Very Low', 'Low', 'Moderate', 'High', 'Very High']
print("Risk Evaluation Scale (1 to 5):")
for i, level in enumerate(risk_levels, 1):
    print(f"{i}: {level} {risk_thresholds[i-1]:.2f} to {risk_thresholds[i]:.2f}")
```

Figure IV-2 the program for risk evaluation scale

IV.2.1.2 Results

The results of the risk level calculation are presented in a structured Risk Evaluation Scale, which categorizes the potential risk scores into five distinct levels. This scale ranges from "Very Low" to "Very High," providing a clear and actionable framework for assessing pest-related risks. The thresholds for each risk level are as follows:

Table IV-13 Risk Level Intervals

Risk level	Intervals
Very Low	0.90 to 1.34
Low	1.34 to 1.78
Moderate	1.78 to 2.22
High	2.22 to 2.66
Very High	2.66 to 3.10

After determining the risk level, I am going know to set the threshold level as indicated in the theoretical foundation of the IPM.

IV.3 The threshold level for the IPM

The primary reason of determining the risk level is to identify the threshold level, which helps us decide when and what actions to implement.

If the risk level is below "high," applying preventive measures helps to maintain control and prevent the situation from escalating. These measures are less costly and less disruptive than corrective actions, making them a sensible choice for lower-risk scenarios.

If the risk level is "high" or above, immediate corrective actions are necessary to mitigate the risk. High-risk situations indicate a more severe problem that requires prompt and decisive action to prevent further escalation and ensure safety.

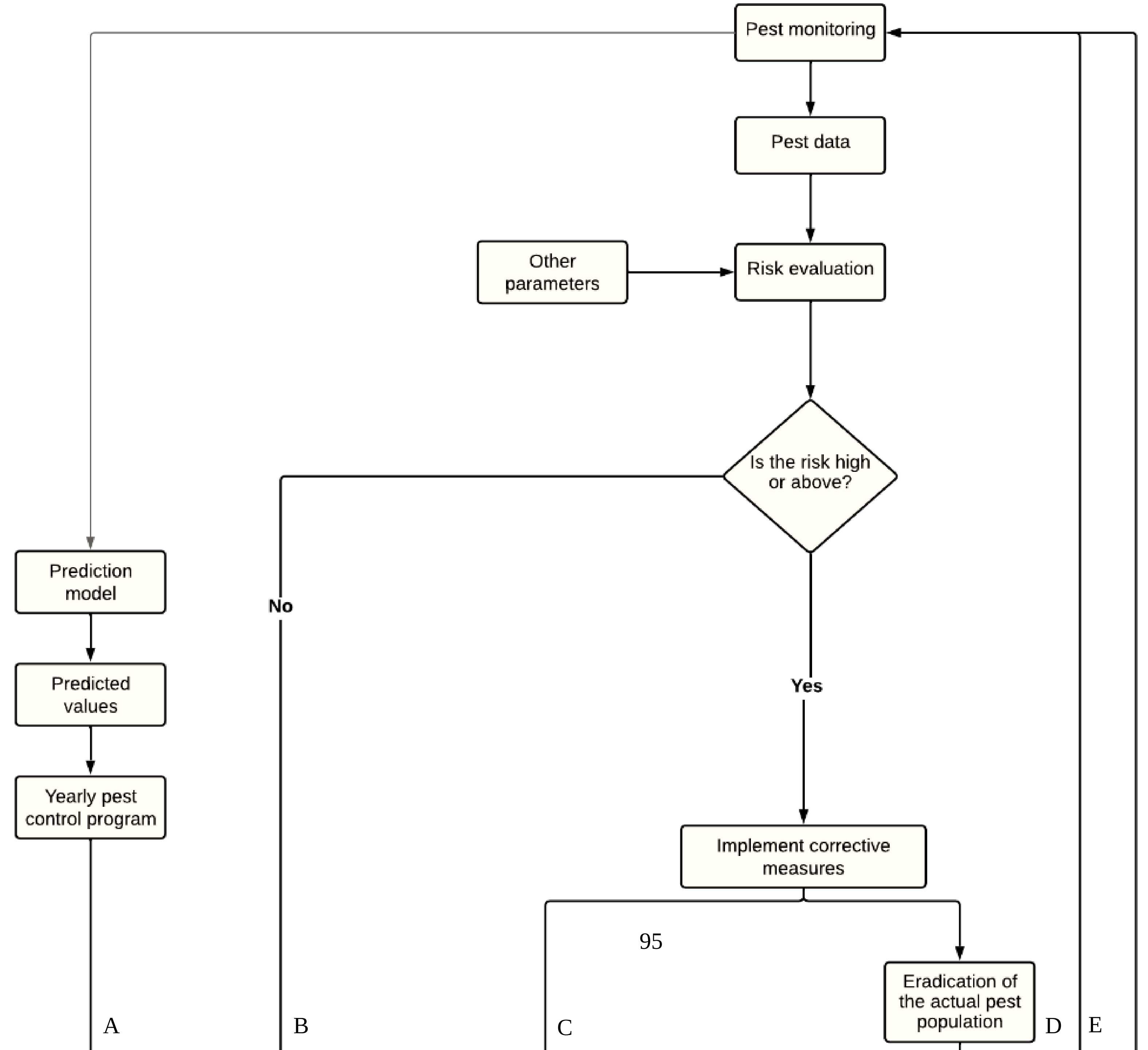
To implement preventive measures, we need to identify the main cause of the problem. This involves checking for entry points, attractants, hiding and breeding places, and means of transport.

Once the main cause is determined, it becomes easier to choose the appropriate action .A standard preventive action is the yearly pest control program, which is continuously improved. Using the prediction model, we can obtain predicted values and use them to enhance the yearly pest control program.

For immediate corrective measures, the use of pesticides is necessary. We rely on experts, typically subcontractors, to apply these pesticides. However, their work must be monitored and recorded. The record should include the type, concentration, location, and date of pesticide application. [37] Applying pesticides does not mean the situation is fully under control; it only addresses the current pest population. Therefore, we must determine the main cause of the problem, similar to the preventive measures, by checking for entry points, attractants, hiding and breeding places, and means of transport. Once identified, appropriate actions can be implemented.

For each implemented measure, we need to record the action and monitor the results. This process feeds back into the evaluation loop and the prediction model improving the yearly pest control program. This cycle ensures continuous improvement (figure IV-3).

Who?	Description	How?
M&Q manager		Collect and analyze the Data
M&Q manager		Choose the pest that you want to evaluate
M&Q manager		Implement your entries in the risk evaluation algorithm
M&Q manager		Decision step
		Implement the data of the previous year in the prediction model
Quality manager		Analyse the predicted values to create the control
Subcont - ractor		Use pesticides or physical methods



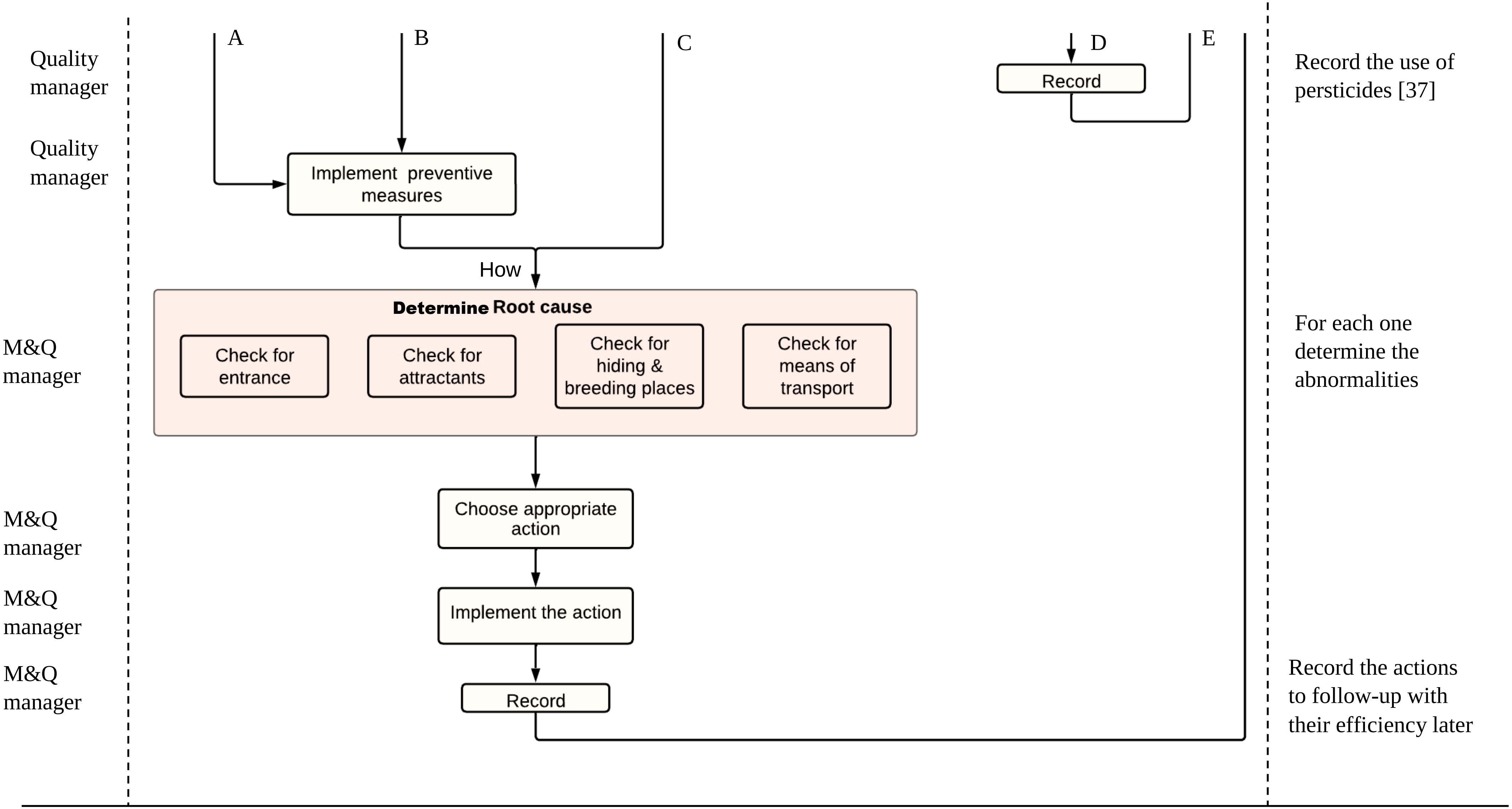


Figure IV-3 Integrated pest management process

IV.4 Integrated pest management interface: $IPM_{1.0}$

The IPM 1.0 interface is truly the fruit of our labor, offering a dynamic tool that assesses and manages pest-related risks. It not only evaluates the current situation but also functions as a robust decision support system, guiding us in choosing the most effective measures for mitigation. By fostering proactive solutions and emphasizing continuous improvement, this system ensures that we mitigate risks to the lowest possible level. I have transitioned from mere procedures and algorithms to a practical, operational solution. Developed using Visual Basic for Applications (VBA), $IPM_{1.0}$ symbolizes my shift towards applying theoretical knowledge in a tangible form. This development not only simplifies complex processes but also bridges various management functions, making it incredibly user-friendly and effective.

In the next section, we will provide a comprehensive description of the $IPM_{1.0}$ interface, assessing its strengths and weaknesses, and exploring potential future directions.

IV.4.1 Description of the interface

The first version of this interface IMP 1.0 includes the following features (Figure IV-3)

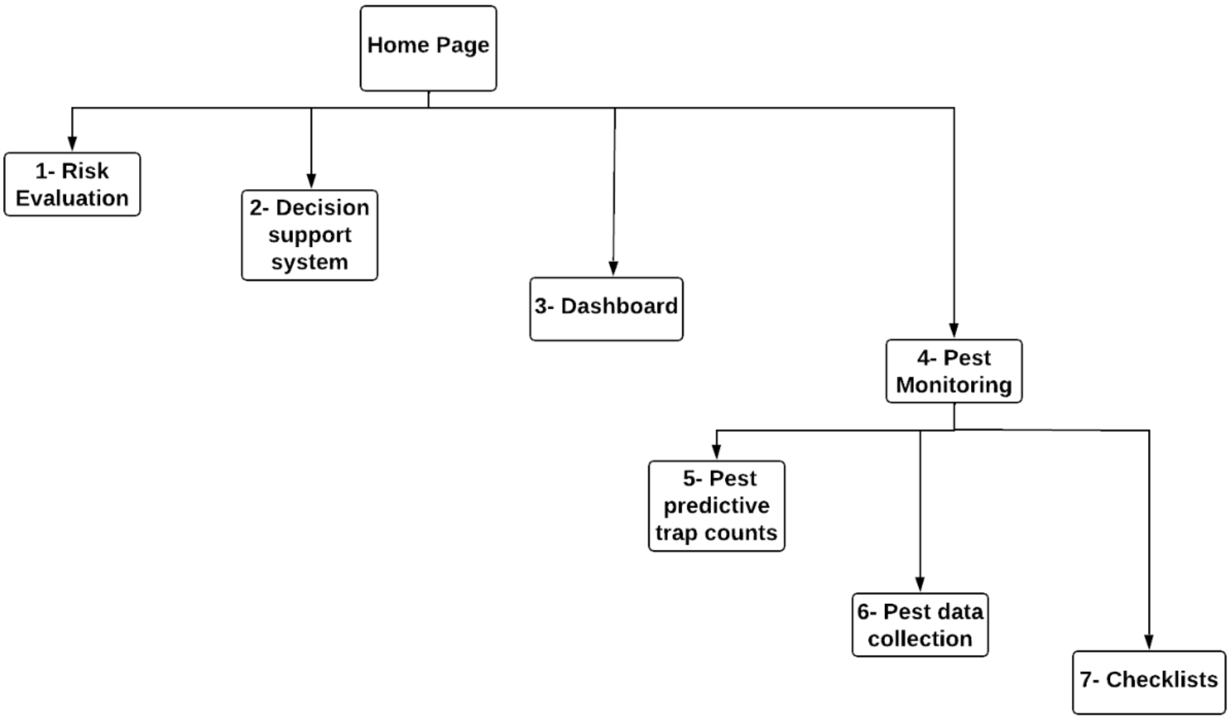


Figure IV-4 IMP_{01} main components

We will go through each one of them and give a specific description of it.

IV.4.1.1 Home page

When you open the interface, the first thing you will get it the home page (figure IV-5).

It serves as the central hub for accessing all features and functionalities represented in the figure:

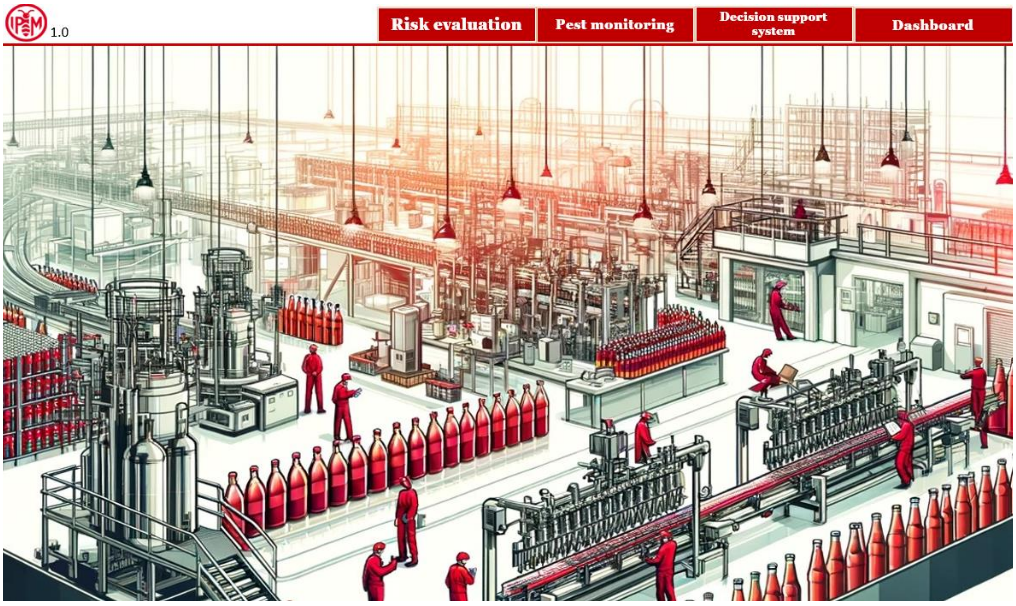


Figure IV-5 Description of IMP 1.0

We will go through each one of them and give a specific description of it.

IV.4.1.2 Risk evaluation page

You access this page by clicking on "Risk evaluation" in the home page. The main feature is the calculation of the risk though a function called "*function_risk*". I developed it on VBA by applying the risk evaluation algorithm **(IV.2).**

Risk Evaluation

Back to menu
Report
Help

DSS Rodents											
Pest Type	Trap Counts	Sign	Zone						Current Sanitary Condition	Season	Risk Level
			ID	Nest Suitability	Food or water Accessibility	Ease of Access	Vulnerability	Score			
Rodents	2	High	ZONE SUD-OUEST	1	1	1	0	3	Good	Spring	High
Rodents	5	Moderate	Dechetterie	0	1	1	0	2	Acceptable	Spring	Moderate
Rodents	0	Low	Magasin PDR froid	0	1	1	0	2	Acceptable	Spring	Low
Rodents	0	Low	Local soutirage ligne verre 30cl & 100cl	1	1	1	1	4	Acceptable	Spring	Moderate
Rodents	0	Low	Chambre froide + Local chimique +CO2+ Gazoil +Local Froid Ammoniac	0	0	0	0	0	Acceptable	Spring	Low
Rodents	2	Moderate	Magasin Stockage préforme	1	0	0	0	1	Acceptable	Spring	Low
Rodents	7	High	Magasin Stockage Sucre	0	1	1	0	2	Good	Spring	High
Rodents	0	Low	Magasin moyens généraux + Stockage des pièces de rechange à l'air libre	1	0	1	0	2	Acceptable	Spring	Low
Rodents	8	High	Magasin annexe stockage pièces d'échanges + Magasin pièces d'échange	1	0	0	0	1	Acceptable	Spring	High

Figure IV-6 Risk evaluation page

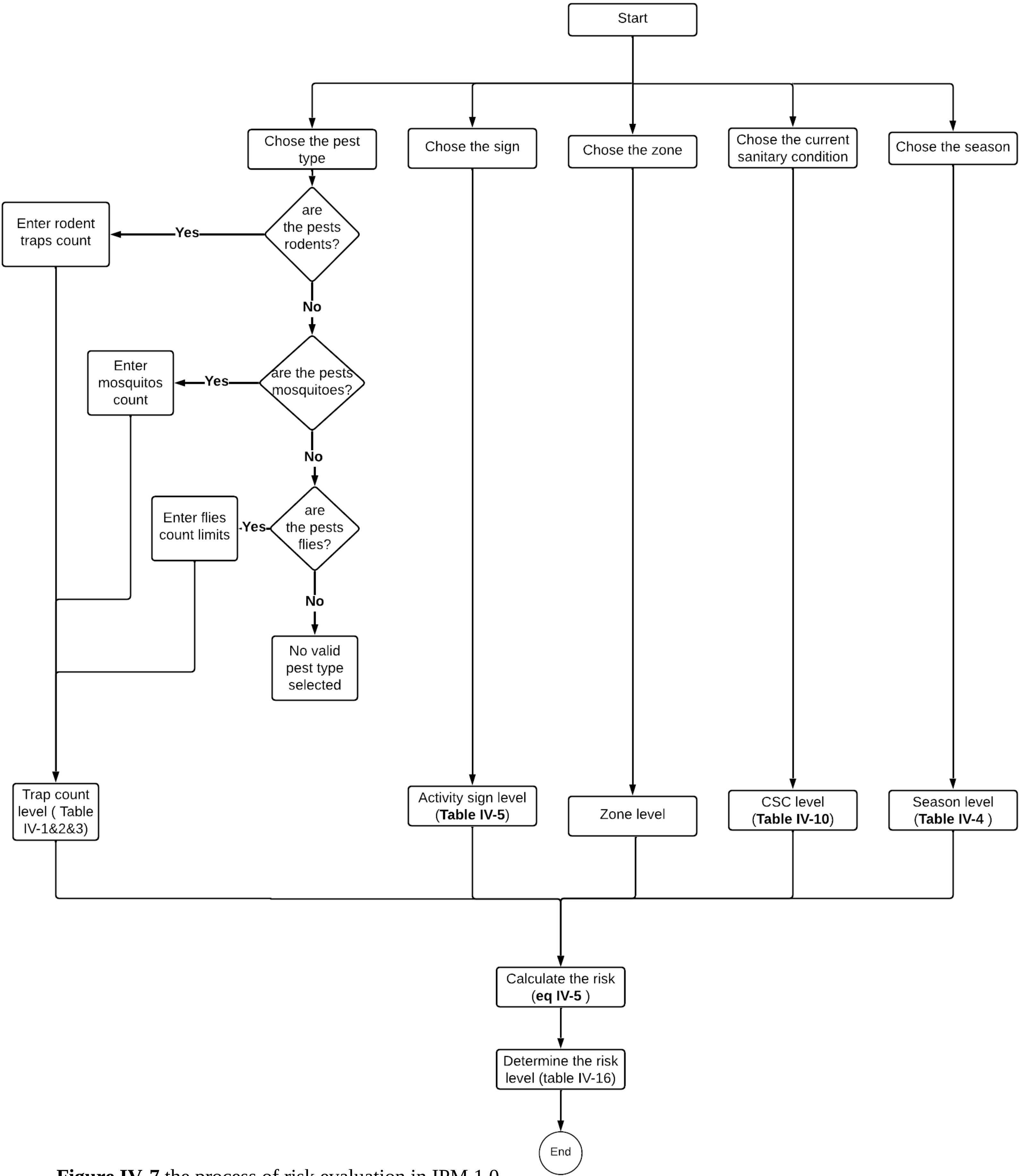


Figure IV-7 the process of risk evaluation in IPM 1.0

This flowchart illustrates the process of evaluating pest-related risks. It begins with the selection of pest-related parameters and progresses through various decision points and data entry steps to calculate the risk level.

IV.4.1.3 Pest monitoring page

When you press on "pest monitoring" in the home page, three new options appear "predicted values", "Checklists" and "Pest data collection". The latter is divided into 4 options "baits consumption", "flies number", "Mosquitoes number" and "other" in case we needed to monitor a new pest temporarily.

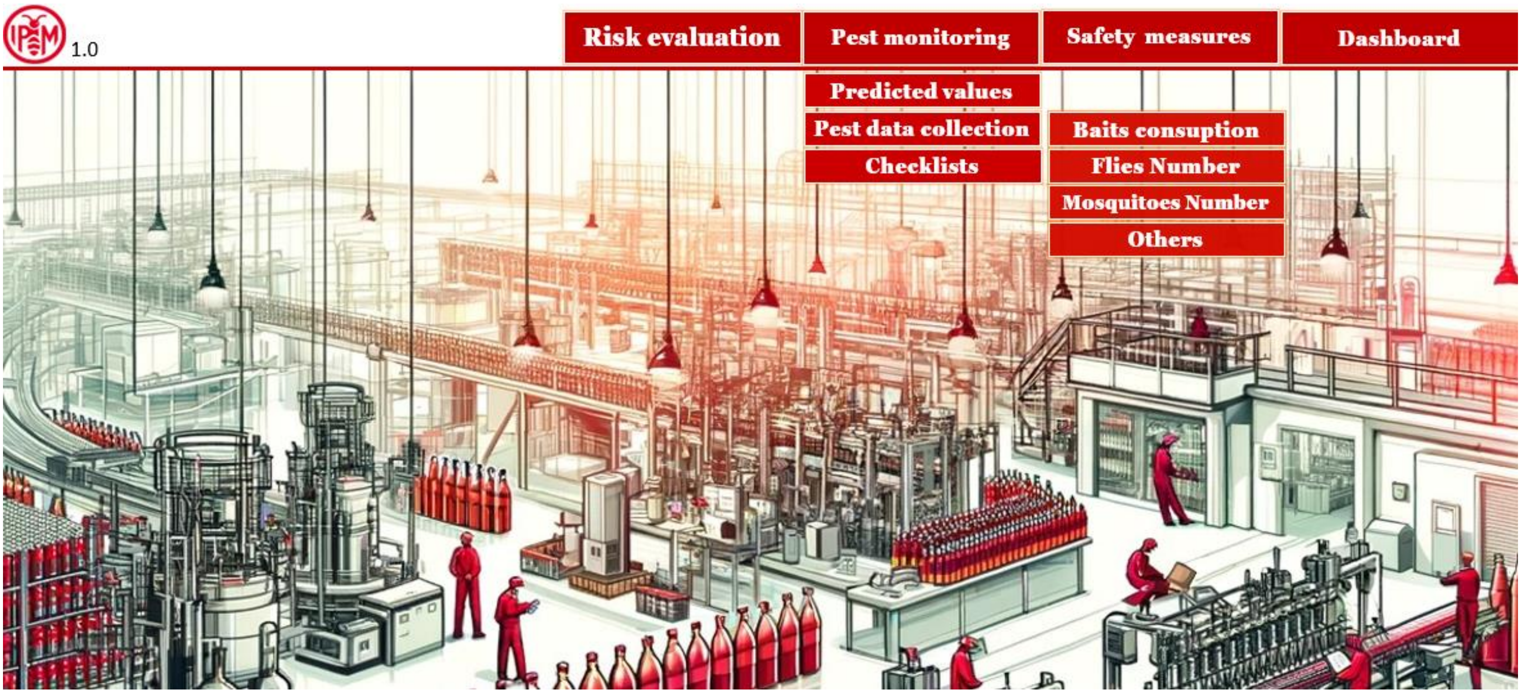


Figure IV-8 Pest monitoring features on the home page

IV.4.1.3.1 Predicted values page

When you run the prediction program (Appendix 9), these predicted values will be sent directly to the predicted values page.

IV.4.1.3.2 Checklists page

When you click on "checklists", you access a page where you can navigate through all the existing checklists for rodents and insects or add your own in the "Others" section. You can use these checklists to track and manage pest control activities and get a compliance level for each one.

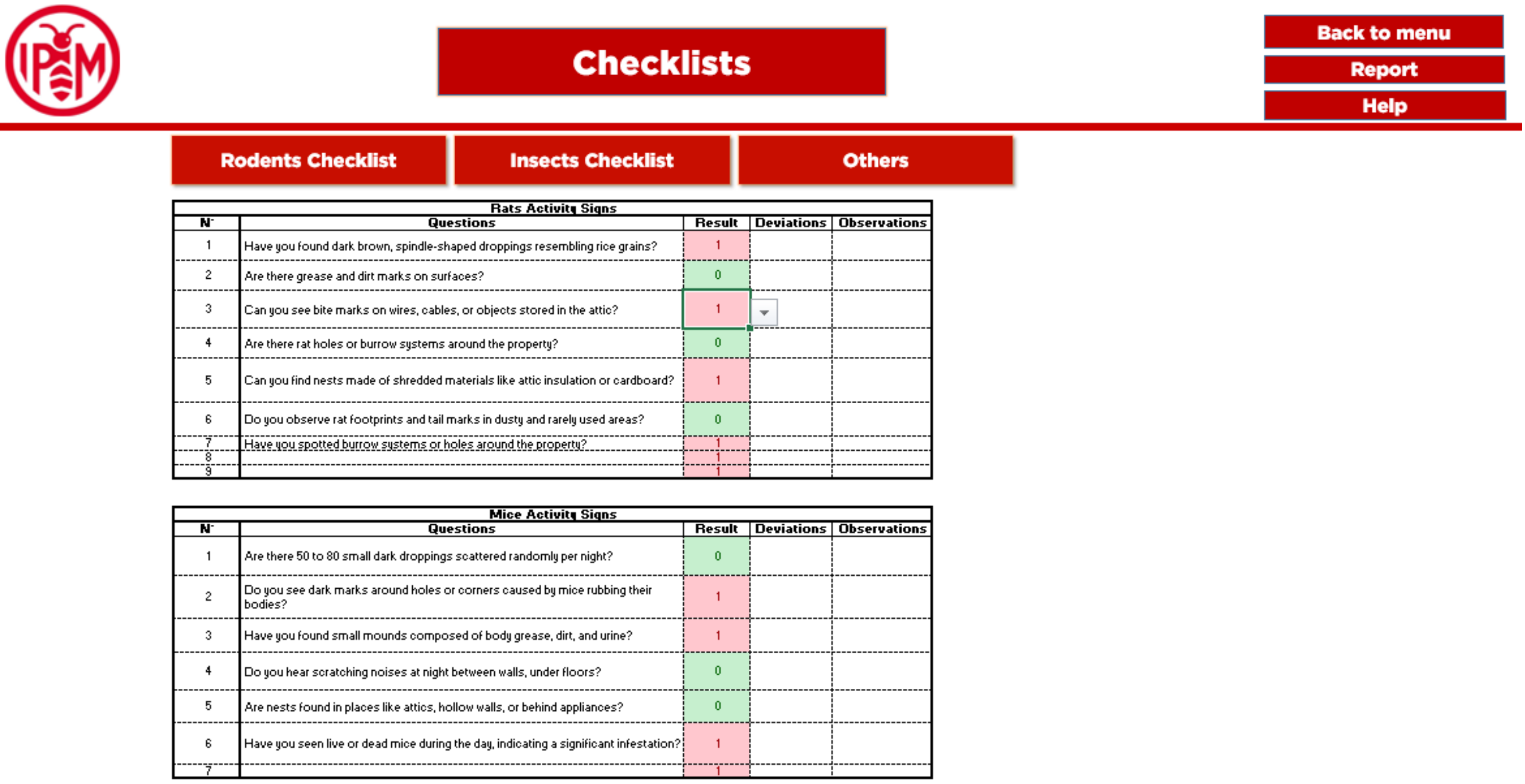


Figure IV-9 Examples of Checklists page

IV.4.1.3.3 Pest data collection page

When you click on "Pest data collection", you will access a new interface that is dedicated specifically to the collection of the data.

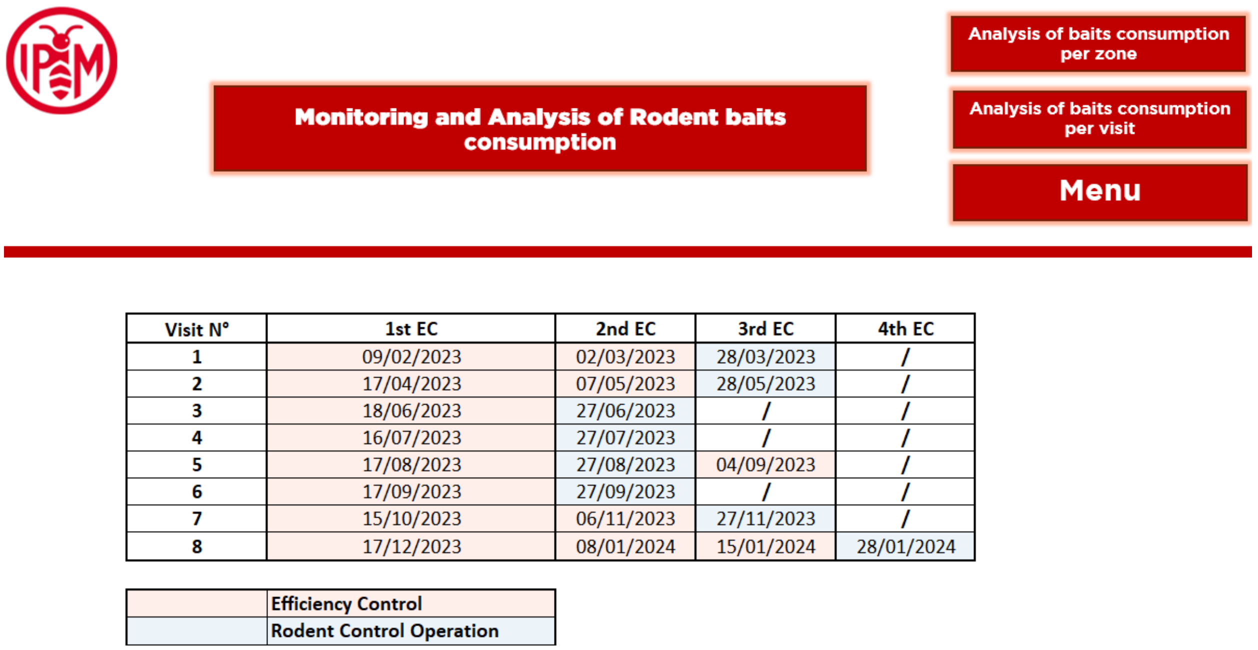


Figure IV-10 Example of the pest data collection home page

The data collection table' template is provided in Appendix 8. In addition to that, you can get an analysis of baits consumption per zone and per visit as it is seen in the figures IV-11 & 12 respectively.

Analysis of Rodent baits consumption per zone

Menu

Annuel program

Zones	Total per zone
Ancienne ligne canette coté Droite	0
Ancienne ligne canette coté Gauche	0
Coté murs extérieur (Can. Ancien)	0
Local stockage concentré partie sèche	0
Local Sucre extérieur	0
Coté Station de pompage N° 01	1
Couloir annexes	2
Entrée Stockage Préforme PET 10/10	0
Sous station Electrique	3
Conditonnement PET 10/10	0
Conditionnement Ligne Verre 30 cl	0
Sortie Conditionnement PET 10/14	0
Local Soufflage PET 10/14	0
Coté Salle de Soufflage PET 14/20- 20/18	0
Magasin Produits Finis (exterieur 14/20)	0
Magasin Produits Finis (exterieur 20/18)	0
Magasin Produits Finis (exterieur CAN KHS)	0
Coté murs ligne 10/14	1
Entrée MPF Vers conditionnement ligne 10/14	1
Entrée MPF Vers ligne 10/14	0
Poste de Gaz	0
Magasin PF (Après Poste de Gaz)	0
Forage 1	0
Groupe Electrogène	0
Compresseur 40 Bars ligne PET 10/10	0
Magasin Production (PR)	0
A coté Local Froid Ammoniac	0
Local Chaudière	2
Magasin MP N° 01	0
Magasin MP,	0
Magasin MP N° 02	0
Magasin PF N° 03	0
Magasin MP N° 04	0
Magasin ancienne ligne injection	5
zone Sud-Ouest (Coté Hôpital)	2

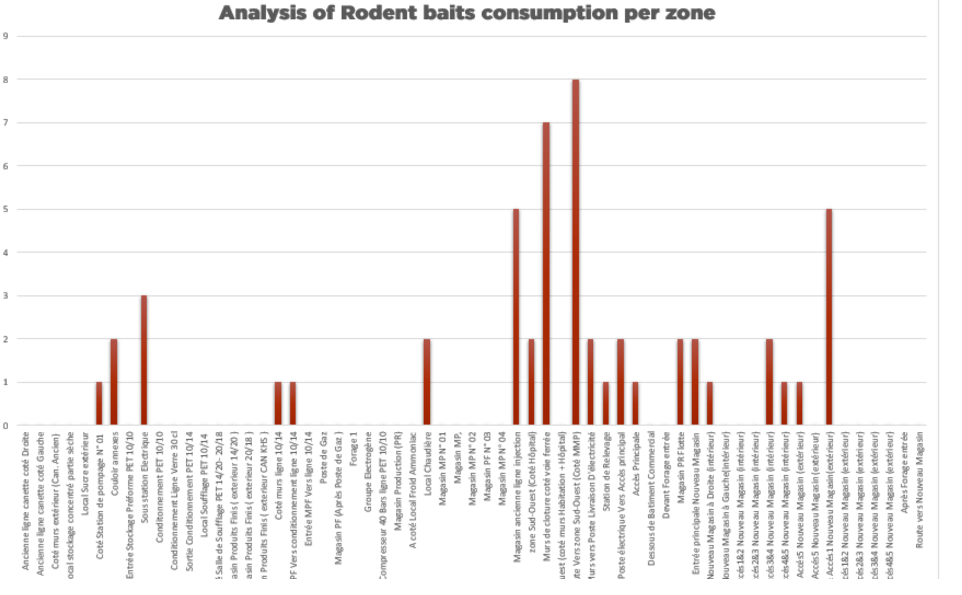


Figure IV-12 Example of the analysis of baits consumption per zone page (2023)

Analysis of Rodent baits consumption

Menu

Annuel programm

		Number of consumed baits
1	1st EC	0
	2nd EC	1
	3rd EC	1
2	1st EC	2
	2nd EC	7
	3rd EC	0
3	1st EC	2
	2nd EC	2
4	1st EC	0
	2nd EC	0
5	1st EC	1
	2nd EC	3
	3rd EC	2
6	1st EC	5
	2nd EC	1
7	1st EC	3
	2nd EC	6
	3rd EC	14
8	1st EC	0
	2nd EC	4
	3rd EC	1
Totale		55

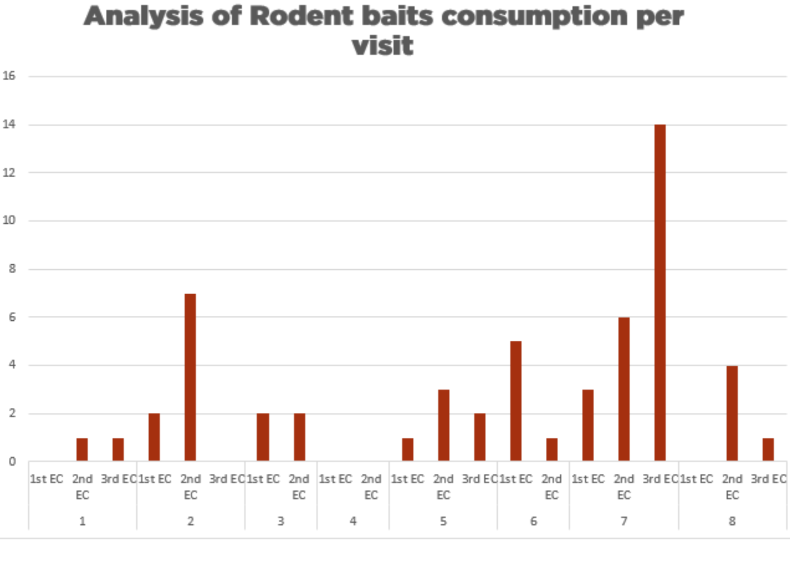


Figure IV-11 analysis of baits consumption per visit page (2023)

IV.4.1.4 Decision Support System (DSS) page

You access this page by clicking on "Decision Support System" in the home page. This has four main functions:

1. If you click on "Start", you will get a new page (figureIV-13). You will have to fill your coordinates and then choose the zone. It will automatically generate the risk level form the risk evaluation already conducted.

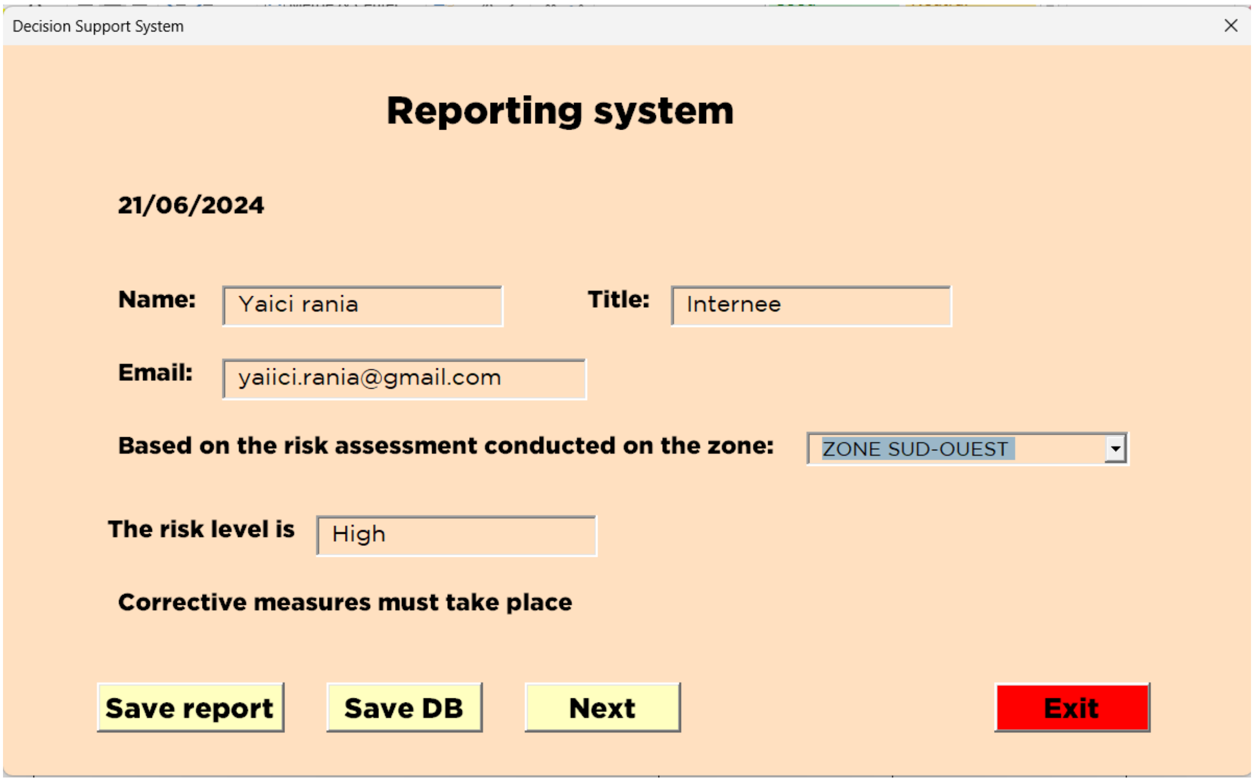


Figure IV-13 Decision support system subpage

2. If the risk is high, you will have to record the use of pesticide by clicking next, [37], eradication section from the PRP-RQ-018 (figure IV-15).

3. If the risk is under high, you will have to choose the adequate prevention measure against your problem by clicking on next (figure IV-14).

4. Finally, you will have the possibility to save your work by clicking on:

- ✓ Save report: to save it in a word file into a specific template for either the preventive or corrective measures (Appendix 10 & 11);
- ✓ Save DB: to save it on your data base;

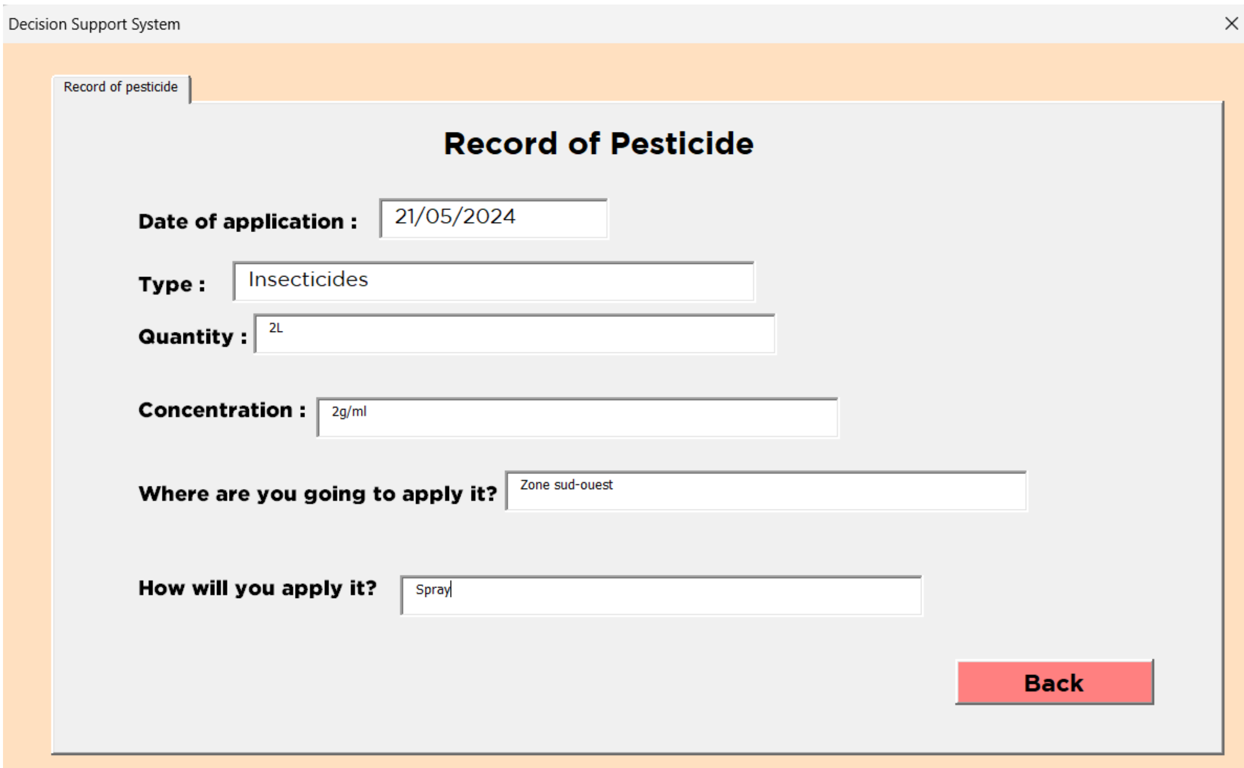


Figure IV-15 Example of pesticide record

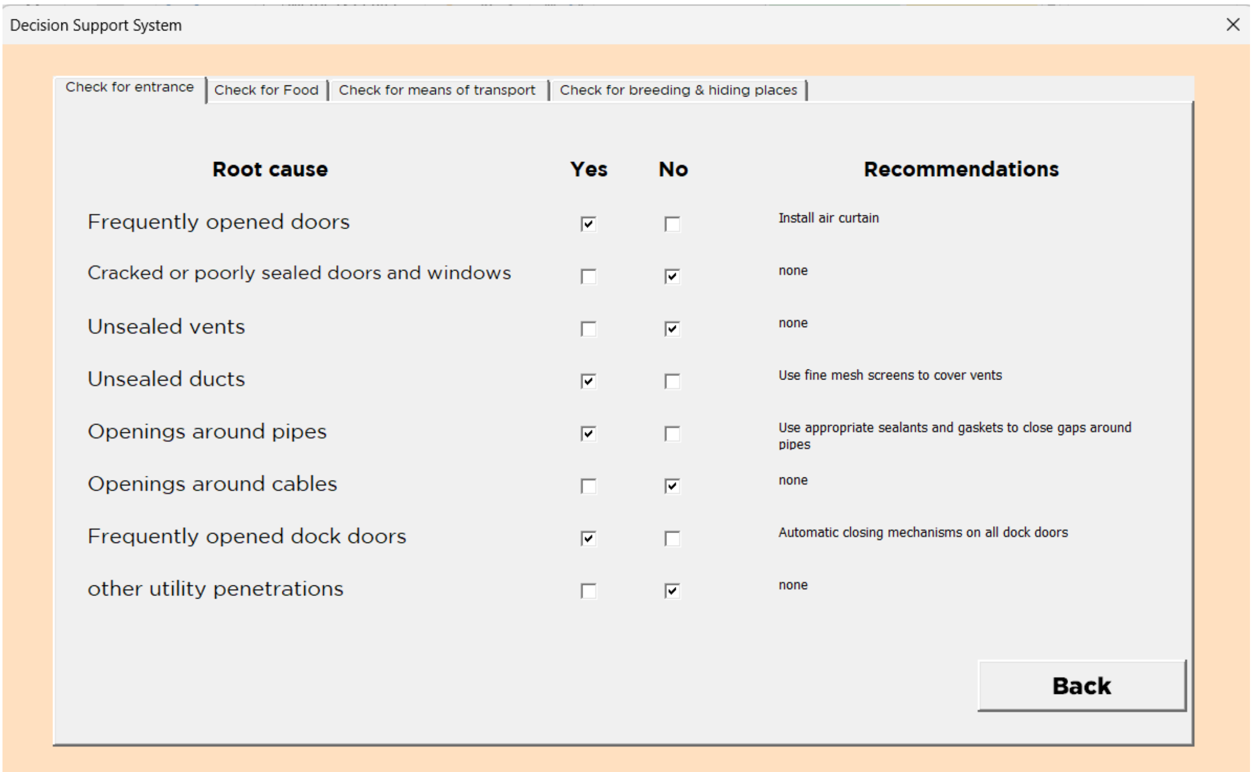


Figure IV-14 Example of recommendations for preventive measures

IV.4.2 Assessing the strengths and improvement areas of the $IMP_{1.0}$

$IPM_{1.0}$ is the outcome of my extensive research and development efforts that integrates all stages of pest management—from identification and monitoring to response and prevention.

One of the interface's key strengths **is** the data driven decision-making. This latter allows the user to anticipate pest behaviors and effectively mitigating risks before they escalate. Another key strength would be the flexible architecture allows it to be interconnected within the company using platforms like OneDrive. Additionally, it retains functionality offline, although reporting features require online access. Furthermore, I developed the user interface using Visual Basic for Applications (VBA), making it accessible to users with varying levels of technical expertise, which significantly enhances user adoption and operational efficiency. The system's design is also flexible, allowing for easy updates and adjustments in response to evolving pest dynamics or new regulatory requirements.

Despite these strengths, there are several areas where $IPM_{1.0}$ could be further developed. Currently, the system is tailored to manage only flies, mosquitoes, and rodents. Expanding this to include a wider array of pests would enhance its utility. In addition, the system's recommendations for preventive measures are limited. Integrating a richer database of proven preventive strategies could provide users with a richer array of options tailored to specific pest threats. Finally, $IPM_{1.0}$ lacks the financial analysis tools. This will help the user to make cost-effective decisions.

Through these improvements, I aim to transform $IPM_{1.0}$ into a more versatile and accessible tool, making it indispensable for effective pest management across a variety of industries.

IV.5 Action review

After the partial implementation of our action plan, a critical review of our progress has been conducted. The implementation of an integrated management system, alongside the development of a robust pest control procedure, a comprehensive pest analysis, an effective assessment of the pest control program, and the establishment of a detailed database documenting pesticide use have collectively contributed to significant advancements in our operations.

These measures have allowed us to not only meet but also exceed our initial compliance target. While our starting compliance level was 70%, our current compliance stands impressively at 81%

(Appendix 12). this achievement not only underscores the effectiveness of the actions taken but also highlights the potential for further improvements.

In addition to the significant improvements in compliance and operational practices already discussed, it is crucial to highlight that the strategies I have implemented are not fixed. They serve as adaptable templates that can be refined and adjusted as necessary. This flexibility is a key feature of my approach, as the work we have conducted goes beyond mere tool development; I have created a holistic management framework. This framework allows for deep, systemic changes that can be tailored to meet evolving needs and challenges.

IV.6 Conclusion

In this chapter, I detailed the implementation of the Integrated Pest Management (IPM) system, focusing initially on designing a dynamic risk evaluation algorithm. This algorithm utilizes a variety of parameters, such as trap counts, activity signals, and seasonal variations, to efficiently analyze pest threats. Due to the complexity of these parameters, I employed the Analytic Hierarchy Process (AHP) to enhance the precision of the assessments. Establishing clear risk levels was crucial in creating a data-driven pest control process, around which the IPM loop was detailed.

To facilitate the utilization of the developments, I created a specialized interface, IMP1.0, using Visual Basic for Applications (VBA). This interface serves not just as a tool, but also as a bridge linking theoretical research with practical application, thus enhancing user interaction and operational efficiency. Despite the successes of IPM 1.0, there are still opportunities for further enhancements.

Looking ahead, I plan to continue improving the IPM 1.0 system to meet emerging challenges in pest management, ultimately aiming to enhance food safety and operational efficiency across various sectors.

IV.7 Future insight of $IPM_{1.0}$

IPM 1.0 presents a remarkable opportunity to be developed as a startup. Therefore I decided to create a Business model canva to define our key partners, activities, and resources while identifying our value propositions and understanding our customer segments. By focusing on customer relationships and channels, we can create effective strategies for market entry and expansion. Moreover, the BMC helps us evaluate our cost structure and revenue streams, ensuring we build a financially viable business model. The BMC is detailed in the table IV-15 below :

Table IV-15 IPM's business model canva

Key Partners

- Strategic alliances with food safety regulatory bodies to ensure compliance and endorsement.
- Collaboration with universities and research institutions for continuous technological advancements.
- Software development firms for additional technical expertise and scaling capabilities.

Key Activities

- Software development: Continual refinement of capabilities.
- Marketing: Highlighting benefits and ROI.
- Customer support: Maximizing user value through engagement.

Key Resources

- A team of software developers skilled in VBA and data analytics platforms.
- Pest management experts to guide the development and update of algorithms.
- Sales and marketing team to promote the interface and handle customer relations.

Value Propositions

- Integrates risk assessment, predictive modeling, and real-time monitoring capabilities.
- Offers food industry facilities enhanced control over pest-related risks.
- Ensures compliance with food safety standards

Customer Relationship

- Dedicated support team providing onboarding and ongoing technical assistance.
- Regular updates and customization options based on customer feedback.
- Community building through forums and user groups for sharing best practices

Channels

- Direct sales via the official product website.
- Partnerships with industrial equipment distributors and food safety consultants.
- Trade shows and industry conferences focused on food production and safety.

Customer Segments

- Primary target: Food processing plants, bottling companies, and large-scale agricultural producers.
- Secondary target: Pest control service companies looking for advanced tools to offer better services to their clients.

Cost Structure

- Development costs: Salaries for developers, cost of technological tools and software licenses.
- Marketing and sales: Advertising, promotional materials, participation in trade shows.
- Customer support: Staffing, training, and support infrastructure

Revenue Stream

- Subscription-based model: Monthly or annual licenses for different module features.
- On-premise installation fee for larger corporations requiring integrated systems.
- Consultancy services for setup, customization, and advanced training

Conclusions & Recommendations

Equatorial Coca-Cola Bottling Company (ECCBC) entrusted me with the mission of evaluating their pest control system and improving it to ensure adherence to Coca Cola’s global standards and identify key challenges in maintaining effective pest management. The primary goal was to address the increasing challenges of maintaining food safety and quality, particularly due to the presence of pests. This involved understanding the specific challenges ECCBC faces in maintaining effective pest control within their facilities, optimizing pest control programs through detailed data analysis, and improving traditional pest management practices to effectively mitigate pest-related risks.

To achieve this, I employed complementary approaches. First, I conducted a comprehensive evaluation of ECCBC's pest control measures against the KORE PRP-RQ-018 requirements. This step included creating a compliance checklist, setting assessment criteria, and analyzing the results. The evaluation showed a compliance level of 70%, reflecting strong adherence in many areas while also revealing key areas for improvement.

To address these gaps, I developed an action plan prioritizing several key measures. The highest priority was conducting a thorough pest analysis, which identified the primary pests and their environmental influences. This analysis facilitated the identification of both internal and external environmental factors affecting pest behavior. By evaluating the facility's zones using criteria such as attractions and vulnerability, I was able to pinpoint the most influential areas.

The pest analysis highlighted the limitations of the current strategies and underscored the potential for integrating new technologies. However, the primary issue identified was the absence of a cohesive pest management system. To address these issues, I analyzed the existing data, using rodent trap consumption as a case study. This crucial data was neither treated nor analyzed, rendering the task inefficient and unnecessary, despite incurring a significant cost of approximately 10,587 USD annually.

To ensure this data received the attention it deserved and became useful, it was essential to implement a robust data analysis system. Since temperature is one of the influencing factors, I started by studying the relationship between bait consumption and temperature. Visual exploration suggested a correlation, which I confirmed with numerical analysis using Spearman's correlation. The results of correlation coefficients were 0.43, 0.44, and 0.45.This indicated a relationship between temperatures and bait consumption, but the non-linear nature of this relationship suggested that simple linear regression models were inadequate.

Therefore, I employed a personalized model to forecast rodent bait consumption using a combination of Seasonal-Trend decomposition using LOESS (STL), AutoRegressive Integrated Moving Average (ARIMA), and Exponential Smoothing models. The predicted values aligned with historical patterns, showing seasonal peaks that reflected past consumption trends. The forecast effectively captured these cyclical patterns, demonstrating the robustness of the manual ARIMA model. Based on these findings, I suggested that ECCBC allocate resources by intensifying pest control measures during high activity periods, especially in May, September, and November. While they should focus on preventive measures and maintenance during low activity periods in December, January, and February in other words; the winter period

In addition to data analysis, I detailed the implementation of the Integrated Pest Management (IPM) system, focusing initially on designing a dynamic risk evaluation algorithm. This algorithm utilizes trap counts, activity signs, seasonal variations, current sanitary conditions, and zone scores to analyze pest threats. I then established the risk level limits, creating a data-driven pest control process, around which the IPM loop was detailed. To facilitate the utilization of the developments, I created a specialized interface, IPM1.0, using Visual Basic for Applications (VBA). This approach allowed me to improve traditional pest management practices through the implementation of the risk algorithm, and make data-driven decisions.

The implemented solutions not only that, it enhanced the compliance to the KORE standard to 80%, making a great progress.

The methodologies and solutions developed in this thesis are not limited to ECCBC alone. The principles of dynamic risk evaluation, data-driven decision-making, and user-friendly interfaces can be applied across various industries and sectors. Any organization dealing with pest management challenges can benefit from this strategy.

The dynamic nature of the predictive models ensures their adaptability to different types of pests and varying environmental conditions. By incorporating more data, the accuracy of the forecasts improves, allowing for more precise and effective pest control measures. This adaptability makes the system relevant and useful across different scenarios, providing reliable forecasts regardless of the type of pest data integrated.

Furthermore, the emphasis on continuous monitoring, threshold-based decision-making, immediate actions, and preventive measures forms a robust framework for pest management. This cyclic and adaptive approach ensures ongoing improvements and responsiveness to changing conditions, making it suitable for various operational contexts.

During the realization of this work, several meetings took place with technical staff to explain the functionalities of the final product. I presented the latest version to the heads of ECCBC and COCA COLA GLOBAL as well. The IPM1.0 was very appreciated by both companies, even in its primary version.

These companies are considering adapting it and investing in its development. I have received opportunities with both companies. ECCBC suggested integrating me into their team as an employee to continue developing the interface. While the Coca-Cola team suggested transforming it into a startup, providing me with their database, expertise, and financial support. The vision is to grow and expand the interface to cover more pests and include functionalities to cover all the pest-related issues in Africa and south Asia. Since these areas suffer the most, the model should be shaped to be even stricter.

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Appendix 1: Coca Cola Technical KORE PRP-RQ-018

Appendix 2: ECCBC' Compliance Review to PRP-RQ-018 GMP Pest Control

ID	Requirement	Evidence	Compliance	Improvement
General	How can we integrate an effective pest management system to enhance overall food safety and quality within our production facilities?		0%	IPM implementation
	How is your pest control program documented to identify target pests?	PC plan PC methods PC schedules	80%	Create PC procedures reevaluate PC methods
	Does the analysis effectively cover the common types of pests and animals, considering their presence in various environments?		0%	Conduct pest analysis, must contain: - Pest types - Relationship between pests and their habitats - Influence of local environmental characteristics on pest presence - Pest control strategies - Impacts of pest infestations
	To what extent does the design of the pest control program incorporate considerations of the external surrounding environment?		0%	Conduct Environmental Impact Assessment reports Site-specific risk assessments (specific élements of the external environment, and the type of vegetation present in the area)

	How effectively does the design of the pest control program assess local surrounding businesses to identify potential pest attractions?		0%	The pest analysis includes an evaluation of nearby local businesses to identify the types of pests that might be attracted to their activities or operations.
	To what extent does the developed pest control program address the effectiveness of pest management measures relative to the proximity to the point of manufacturing?	Plant diagram of the control measures	60%	Pest control measures optimized based on the distance from the manufacturing point (systematic approach)
	How effectively does the implemented pest control plan ensure that all chemicals and traps comply with local legislation and do not pose a risk to employees, products, or the environment?	Documentation of regulatory compliance safety protocols in place to protect employees, products, and the environment regarding chemical and trap usage	80%	Risk assessments
Pest Control Responsibilities	How effectively do operations contracting pest control services to a third-party ensure that the contractor possesses the necessary capabilities, training, and understanding to conduct pest control activities in food manufacturing facilities?	Review the contracting process documentation Training programs Qualification checks Training certifications Prior experience evaluations of the contractor	100%	
	How regularly are audits conducted on the pest control program to verify its effectiveness?	Audit Schedule Audit Reports	100%	

Preventing access	How consistently are buildings maintained in good repair, and are potential pest access points such as holes and drains adequately sealed?	Maintenance Records Inspection Reports Repair Documentation Pest Activity Reports Employee Training	60%	
	How effectively are external doors, windows, and ventilation openings designed to minimize the potential for entry of pests?	Design Specifications Maintenance Records Pest Exclusion Measures	60%	
	Are all doorways appropriately sealed at ground level to prevent rodent entry?	Inspection Reports Seal Verification Maintenance Records Pest Activity Reports	60%	
	How are frequently used doorways managed to prevent entry of birds and other pests?	Verify if frequently used doorways are equipped with overlapping plastic curtain strips or high-speed roller doors to deter entry of birds and insects.	80%	

	Are suitable prevention devices used in areas where the potential for bird activity exists?	-Verify if suitable prevention devices such as bird spikes, nets, or deterrents are installed in areas prone to bird activity. -Check maintenance logs for documentation of installation, inspection, and maintenance of bird prevention devices.	80%	Conduct bird activity assessment
	Are air curtains utilized on doors to processing areas as a deterrent to the entry of flying insects?		0%	Install Air Curtains in essential entrances and near white zone
Harborage and infestations	How are your storage practices designed to minimize the availability of food and water to pests?	Documentation of storage practices : procedures that ensure food and water sources are minimized for pests	60%	Consider the effectiveness of the procedures
	Describe the processes included in your incoming material receiving program to inspect materials and shipping devices for pests.	Inspection logs. Records demonstrating regular inspection of materials and shipping devices for pests.	100%	

	How do you inspect incoming ingredients and package integrity for signs of pest infestation?	Checklists or guidelines for inspection, including specific areas to inspect (e.g., underside of carton flaps, bag/sack folds).	100%	
	What procedures are in place to immediately isolate materials found to be contaminated with pests?	Incident reports / logs showing instances of contamination The isolation procedure for contaminated material	100%	
	How do you manage materials found to be infested with pests, especially in terms of using or disposing of these materials?	Documentation of disposal methods to prevent infestation risk	60%	Procedures for pest elimination from infested materials
	What process is in place for inspecting pallets for pest activity before use within the facility?	Checklists used for assessing pallets for pest activity.	100%	
	How do you maintain the facility grounds to prevent areas of infestation?	Maintenance schedules Practices for waste storage Photographs showing well-drained grounds	60%	Photographs showing dirty grounds

	Could you provide documentation that illustrates how your facility's waste storage, including the use of trash compactors and refuse containers, is managed to prevent pest attraction and harborage, and how these are maintained in a sanitary manner?	For trash compactors and refuse containers : Procedures for storing waste and maintaining Maintenance and Cleaning Schedules	100%	
	How your waste storage practices are designed to prevent pest attraction and harborage, including details on storage methods, frequency of waste removal, and staff training on these practices?	Waste storage guidelines Records and logs that show how frequently waste is collected and removed from the facility Waste Inspection Logs Pest Control Reports	60%	
	What measures are in place to avoid the build-up of old machine/equipment parts or building materials that could harbor pests?		0%	Records of regular clean-ups Disposal Procedures Documentation: Providing procedures for the proper disposal of old machine/equipment parts and building materials
	How are areas within the facility where infestation may occur identified and included in routine inspection and pest control activities?	Documentation of : - Identified common locations for pest harborage (cracks in walls or floor tiles, around drains, roof cavities, dark and damp locations)	100%	

		- Pest control intervention records.		
Monitoring and detection	Can you provide detailed evidence of your pest-monitoring program, specifically regarding the placement of detectors and traps throughout the facility ?	Map of Detectors and Traps Pest-Monitoring Program including: Objectives Specifications of the detectors and traps used (robust, tamper-resistant construction appropriate for the target pest)	80%	Pest-Monitoring Program including: Processes for the placement of detectors and traps
Eradication	What immediate eradication measures are implemented after evidence of pest infestation is reported, and how do these measures comply with local regulations?	Local regulations Action plan for eradication measures Records of previous infestation	100%	
	How do you ensure clean-up activities from infestations, such as bird nests or droppings, prevent the spread of disease or contamination?	Clean-up protocol	100%	

	Can you demonstrate that pesticide use and application are restricted to trained operatives and controlled to avoid product safety hazards?	Policies on pesticide use Training records for operatives handling pesticides	100%	
	How are records of pesticide use maintained, detailing type, quantity, concentrations used, application details, and target pest?	Chemical inventory records	40%	Logs or databases of pesticide use
	Are exterior monitoring devices or bait stations for rats and mice tamper-resistant, anchored, and properly labeled?	Inventory or descriptions of devices/bait stations used installation records showing compliance with : - Monitor monthly	80%	Position at 15 to 30-meter (50 to 100-foot) intervals along exterior perimeter walls and elsewhere if appropriate
	What internal control programs are in place for pest management, and do they comply with legal and safety standards?	Program documentation Compliance reports Audit findings	100%	
	How are electric flying insectocutors placed to avoid attracting insects inside the plant and prevent contamination?	Installation records Maintenance logs	80%	Effectiveness assessments
Total			70%	

Appendix 3: Classification of Internal Zone according to the attractions and vulnerability

Zone	Nest Suitability	Food or water Accessibility	Ease of Access	Vulnerability	Score
ZONE SUD-OUEST	1	1	1	0	3
Dechetterie	0	1	1	0	2
Magasin PDR froid	0	1	1	0	2
Local soutirage ligne verre 30cl & 100cl	1	1	1	1	4
Chambre froide + Local chimique +CO2+ Gazoil +Local Froid Ammoniac	0	0	0	0	0
Magasin Stockage préforme	1	0	0	0	1
Magasin Stockage Sucre	0	1	1	0	2
Atelier flotte	1	0	1	0	2
Magasin annexe stockage pièces d'échanges + Magasin pièces d'échange	1	0	0	0	1
Magasin matières premières+ NC	0	1	1	0	2
Local Chaudière	1	1	1	0	3
Magasin PR Production RDC	0	0	1	0	1
Réffectoire 1st floor	1	1	1	0	3
Vestière 1st floor	1	1	1	0	3
Atelier2	1	0	1	0	2
Local sucre	1	1	1		3
Local siroperie	1	1	1	0	3
Local traitement des eaux	1	1	1	0	3
Local soufflage	1	1	0	1	3
Local soutirage	1	1	0	1	3
Local conditionnement	1	0	1	1	3
Local conditionnement ligne verre 30cl & 100cl	1	1	1	1	4
Magasin produits finis	1	1	1	0	3

Appendix 4: Current Pest Control Strategies at ECCBC

Strategy	Description
Building Design and Maintenance	Design and maintain buildings to prevent pest entry and eliminate potential refuges or breeding sites.
Hygiene Monitoring	Conduct regular hygiene inspections during storage of raw materials and finished products to maintain cleanliness and prevent pests.
Immediate Response	Report pest infestations immediately to a pest control contractor for prompt interventions.
Pest Control Measures	Use insect flashes, mechanical traps, glue traps, rodenticides, and insecticides. Plan detailed intervention and inspection schedules.
Access Control	Follow PRP 01 and PRP 02 to keep doors closed except during material and personnel flow.
Preventing Harborage	Store materials off the ground on pallets or racks, maintain a 50 cm space from walls, and isolate and dispose of infested materials.
Monitoring and Detection	Conduct planned control visits and analyze reports.
Eradication	Detail eradication methods and products. Plan prompt interventions for infestations.

Appendix 5 : Pest control program

Appendix 6: Current Practice Gaps

Current Practice	Recommandation
Building Design and Maintenance	Regularly update and inspect building design; integrate IPM principles [39]
Hygiene Surveillance	Increase inspection frequency; use remote monitoring technology; continuous staff training [40]
Immediate Contractor Intervention	Establish an in-house rapid response team; implement digital reporting for quicker communication [41]
Building Layout and Access Control	Automate access control with motion sensors; regular inspection and maintenance of doors and gates [42]
Material Storage Practices	Improve storage practices; conduct routine pest risk assessments
Monitoring and Detection	Deploy advanced monitoring technologies; increase surveillance frequency; use data analytics for trend analysis to create annual program [43]
Eradication Methods	Expand in-house training for minor eradication tasks; use environmentally friendly methods; implement a continuous improvement program

Appendix 7: Internal table used by ECCBC for Data collection

EQUATORIAL COCA-COLA BOTTLING COMPANY ALGERIA	Monitoring du Contrôle de DERATISATION		QSE ER 99/2 Page 1/1
	Date de rédaction: 03/03/2021	Remplace: QSE ER 99/1	Du: 20/02/2020

Lieu : Site Rouiba Usine

Secteur :

Date du 1ère Opération: 15/01/2023

Endroits Controlés	Opération effectuées	1ère Contrôle d'efficience d'appattage	2ème Contrôle d'efficience d'appattage	3ème Contrôle d'efficience d'appattage	4ème Contrôle d'efficience d'appattage	5ème Contrôle d'efficience d'appattage	Vérification d'efficacité des contrôles (Metrology & Quality Monitoring Manager)
	Dératisation	Date:	Date: 02/03/2023	Date:	Date:	Date:	
Ancienne ligne canette coté Droite			*0*				*OK*
Ancienne ligne canette coté Gauche			*0*				*OK*
Coté murs extérieur (Can. Ancien)			*0*				*OK*
Local stockage concentré partie sèche			*0*				*OK*
Local Sucre extérieur			*0*				*OK*
Coté Station de pompage N° 01			*0*				*OK*
Couloir annexes			*0*				*OK*
Entrée Stockage Préforme PET 10/10			*0*				*OK*
Sous station Electrique			*0*				*OK*
Conditonnement PET 10/10			*0*				*OK*
Conditionnement Ligne Verre 30 cl			*0*				*OK*
Sortie Conditionnement PET 10/14			*0*				*OK*
Local Soufflage PET 10/14			*0*				*OK*
Coté Salle de Soufflage PET 14/20- 20/18			*0*				*OK*
Magasin Produits Finis (exterieur 14/20)			*0*				*OK*
Magasin Produits Finis (exterieur 20/18)			*0*				*OK*
Magasin Produits Finis (exterieur CAN KHS)			*0*				*OK*
Coté murs ligne 10/14			*0*				*OK*
Entrée MPF Vers conditionnement ligne 10/14			*0*				*OK*
Entrée MPF Vers ligne 10/14			*0*				*OK*
Poste de Gaz			*0*				*OK*
Magasin PF (Après Poste de Gaz)			*0*				*OK*
Forage 1			*0*				*OK*
Groupe Electrogène			*0*				*OK*
Compresseur 40 Bars ligne PET 10/10			*0*				*OK*
Magasin Production (PR)			*0*				*OK*
A coté Local Froid Ammoniac			*0*				*OK*
Local Chaudière			*0*				*OK*
Magasin MP,			*0*				*OK*
Magasin MP N° 02			*0*				*OK*
Magasin PF N° 03			*0*				*OK*
Magasin MP N° 04			*0*				*OK*
Magasin ancienne ligne injection			*0*				*OK*
zone Sud-Ouest (Coté Hôpital)			*1*				*OK*
Murs de cloture coté voie ferrée			*0*				*OK*
Route Vers zone Sud-Ouest (coté murs Habitation + Hôpital)			*0*				*OK*
Route Vers zone Sud-Ouest (Coté MMP)			*0*				*OK*
Murs vers Poste Livraison D'électricité			*0*				*OK*
Station de Relevage			*0*				*OK*
Poste électrique Vers Accès principal			*0*				*OK*
Accès Principale			*0*				*OK*
Dessous de Batiment Commercial			*0*				*OK*
Devant Forage entrée			*0*				*OK*
Magasin PR Flotte			*0*				*OK*
Entrée principale Nouveau Magasin			*0*				*OK*
Stockage sucre Nouveau Magasin à Droite (intérieur)			*0*				*OK*
Stockage sucre Nouveau Magasin à Gauche(intérieur)			*0*				*OK*
Entre Accés1&2 Nouveau Magasin (intérieur)			*0*				*OK*
Entre Accés2&3 Nouveau Magasin (intérieur)			*0*				*OK*
Entre Accés3&4 Nouveau Magasin (intérieur)			*0*				*OK*
Entre Accés4&5 Nouveau Magasin (intérieur)			*0*				*OK*
Sortie Accés5 Nouveau Magasin (extérieur)			*0*				*OK*
Après Accés5 Nouveau Magasin (extérieur)			*0*				*OK*
Entre Accés principale & Accés1 Nouveau Magasin(extérieur)			*0*				*OK*
Entre Accés1&2 Nouveau Magasin (extérieur)			*0*				*OK*
Entre Accés2&3 Nouveau Magasin (extérieur)			*0*				*OK*

Entre Accés1&2 Nouveau Magasin (intérieur)			0				OK
Entre Accés2&3 Nouveau Magasin (intérieur)			0				OK
Entre Accés3&4 Nouveau Magasin (intérieur)			0				OK
Entre Accés4&5 Nouveau Magasin (intérieur)			0				OK
Sortie Accés5 Nouveau Magasin (extérieur)			0				OK
Après Accés5 Nouveau Magasin (extérieur)			0				OK
Entre Accés principale & Accés1 Nouveau Magasin(extérieur)			0				OK
Entre Accés1&2 Nouveau Magasin (extérieur)			0				OK
Entre Accés2&3 Nouveau Magasin (extérieur)			0				OK
Entre Accés3&4 Nouveau Magasin (extérieur)			0				OK
Entre Accés4&5 Nouveau Magasin (extérieur)			0				OK
Après Forage entrée			0				OK
Route vers Nouveau Magasin			0				OK
TOTAL			1				

DETAILLE DE CONSOMMATION D'APPATAGE

SECTEUR :

Endroits Controlés	N° des boites Consommées	ETAT DES APPATS	OBSERVATION	ACTION
Ancienne ligne canette coté Droite				
Ancienne ligne canette coté Gauche				
Coté murs extérieur (Can. Ancien)				
Local stockage concentré partie sèche				
Conditionnement PET 10/10				
Conditionnement Ligne Verre 30 cl				
Sortie Conditionnement PET 10/14				
Local Soufflage PET 10/14				
Coté Salle de Soufflage PET 14/20- 20/18				
Magasin Produits Finis (exterieur 14/20)				
Magasin Produits Finis (exterieur 20/18)				
Magasin Produits Finis (exterieur CAN KHS)				
Coté murs ligne 10/14				
Entrée MPF Vers conditionnement ligne 10/14				
Entrée MPF Vers ligne 10/14				
Poste de Gaz (ancienne)				
Magasin PF (Après Poste de Gaz)				
Forage 1				
Groupes Electrogène				
Compresseur 40 Bars ligne PET 10/10				
Magasin Production (PR)				
A coté Local Froid Ammoniac				
Local Chaudière				
Magasin MP N° 01				
Magasin MP,				
Magasin MP N° 02				
Magasin PF N° 03				
Magasin MP N° 04				
Magasin ancienne ligne injection				
Zone Sud-Ouest (Coté Hôpital)	12	ébréché	/	Remplacement d'appât
Murs de clôture coté voie ferrée				
Route Vers zone Sud-Ouest (coté murs Habitation + Hôpital)				
Route Vers zone Sud-Ouest (Coté MMP)				
Murs vers Poste Livraison D'électricité				
Station de Relevage				
Poste électrique Vers Accès principal				
Accès Principale				
Dessous de Batiment Commercial				
Devant Forage entrée				
Magasin PR Flotte				
Entrée principale Nouveau Magasin				
Stockage sucre Nouveau Magasin à Droite (intérieur)				
Stockage sucre Nouveau Magasin à Gauche(intérieur)				
Entre Accés1&2 Nouveau Magasin (intérieur)				
Entre Accés2&3 Nouveau Magasin (intérieur)				
Entre Accés3&4 Nouveau Magasin (intérieur)				
Entre Accés4&5 Nouveau Magasin (intérieur)				
Sortie Accés5 Nouveau Magasin (extérieur)				
Après Accés5 Nouveau Magasin (intérieur)				
Entre Accés principale & Accés1 Nouveau Magasin(extérieur)				
Entre Accés1&2 Nouveau Magasin (extérieur)				

Appendix 8: New template for data collection for each operation

Monitoring and Analysis of Rodent baits consumption

Menu

Annuel programgram

Endroits	1ère Opération		2ème Opération		3ème Opération	
	N° des boites Consommées	Vérification en Interne	N° des boites Consommées	Vérification en Interne	N° des boites Consommées	Vérification en Interne
Ancienne ligne canette coté Droite	0	Validé	0	Validé	0	Validé
Ancienne ligne canette coté Gauche	0	Validé	0	Validé	0	Validé
Coté murs extérieur (Can. Ancien)	0	Validé	0	Validé	0	Validé
Local stockage concentré partie sèche	0	Validé	0	Validé	0	Validé
Local Sucre extérieur	0	Validé	0	Validé	0	Validé
Coté Station de pompage N° 01	0	Validé	0	Validé	0	Validé
Couloir annexes	0	Validé	0	Validé	0	Validé
Entrée Stockage Préforme PET 10/10	0	Validé	0	Validé	0	Validé
Sous station Electrique	0	Validé	0	Validé	0	Validé
Conditionnement PET 10/10	0	Validé	0	Validé	0	Validé
Conditionnement Ligne Verre 30 cl	0	Validé	0	Validé	0	Validé
Sortie Conditionnement PET 10/14	0	Validé	0	Validé	0	Validé
Local Soufflage PET 10/14	0	Validé	0	Validé	0	Validé
Coté Salle de Soufflage PET 14/20- 20/18	0	Validé	0	Validé	0	Validé
Magasin Produits Finis (exterieur 14/20)	0	Validé	0	Validé	0	Validé
Magasin Produits Finis (exterieur 20/18)	0	Validé	0	Validé	0	Validé
Magasin Produits Finis (exterieur CAN KHS)	0	Validé	0	Validé	0	Validé
Coté murs ligne 10/14	0	Validé	0	Validé	0	Validé
Entrée MPF Vers conditionnement ligne 10/14	0	Validé	0	Validé	0	Validé
Entrée MPF Vers ligne 10/14	0	Validé	0	Validé	0	Validé
Poste de Gaz	0	Validé	0	Validé	0	Validé
Magasin PF (Après Poste de Gaz)	0	Validé	0	Validé	0	Validé
Forage 1	0	Validé	0	Validé	0	Validé
Groupe Electrogène	0	Validé	0	Validé	0	Validé
Compresseur 40 Bars ligne PET 10/10	0	Validé	0	Validé	0	Validé
Magasin Production (PR)	0	Validé	0	Validé	0	Validé
A coté Local Froid Ammoniac	0	Validé	0	Validé	0	Validé
Local Chaudière	0	Validé	0	Validé	0	Validé
Magasin MP N° 01	0	Validé	0	Validé	0	Validé
Magasin MP.	0	Validé	0	Validé	0	Validé
Magasin MP N° 02	0	Validé	0	Validé	0	Validé
Magasin PF N° 03	0	Validé	0	Validé	0	Validé
Magasin MP N° 04	0	Validé	0	Validé	0	Validé
Magasin ancienne ligne injection	0	Validé	0	Validé	0	Validé
zone Sud-Ouest (Coté Hôpital)	0	Validé	1	Validé	0	Validé
Murs de cloture coté voie ferrée	0	Validé	0	Validé	0	Validé
Route Vers zone Sud-Ouest (coté murs Habitation + Hôpital)	0	Validé	0	Validé	0	Validé
Route Vers zone Sud-Ouest (Coté MMP)	0	Validé	0	Validé	0	Validé
Murs vers Poste Livraison D'électricité	0	Validé	0	Validé	0	Validé
Station de Relevage	0	Validé	0	Validé	0	Validé
Poste électrique Vers Accès principal	0	Validé	0	Validé	0	Validé
Accès Principale	0	Validé	0	Validé	0	Validé
Dessous de Batiment Commercial	0	Validé	0	Validé	0	Validé
Devant Forage entrée	0	Validé	0	Validé	0	Validé
Magasin PR Flotte	0	Validé	0	Validé	0	Validé
Entrée principale Nouveau Magasin	0	Validé	0	Validé	0	Validé
Stockage sucre Nouveau Magasin à Droite (intérieur)	0	Validé	0	Validé	0	Validé
Stockage sucre Nouveau Magasin à Gauche(intérieur)	0	Validé	0	Validé	0	Validé
Entre Accés1&2 Nouveau Magasin (intérieur)	0	Validé	0	Validé	0	Validé
Entre Accés2&3 Nouveau Magasin (intérieur)	0	Validé	0	Validé	0	Validé
Entre Accés3&4 Nouveau Magasin (intérieur)	0	Validé	0	Validé	1	Validé
Entre Accés4&5 Nouveau Magasin (intérieur)	0	Validé	0	Validé	0	Validé
Sortie Accés5 Nouveau Magasin (extérieur)	0	Validé	0	Validé	0	Validé
Après Accés5 Nouveau Magasin (extérieur)	0	Validé	0	Validé	0	Validé
Entre Accés principale & Accés1 Nouveau Magasin(ext	0	Validé	0	Validé	0	Validé
Entre Accés1&2 Nouveau Magasin (extérieur)	0	Validé	0	Validé	0	Validé
Entre Accés2&3 Nouveau Magasin (extérieur)	0	Validé	0	Validé	0	Validé
Entre Accés3&4 Nouveau Magasin (extérieur)	0	Validé	0	Validé	0	Validé
Entre Accés4&5 Nouveau Magasin (extérieur)	0	Validé	0	Validé	0	Validé
Après Forage entrée	0	Validé	0	Validé	0	Validé
Route vers Nouveau Magasin	0	Validé	0	Validé	0	Validé
TOTAL	**0**	**Succès**	**1**	**Succès**	**1**	**Succès**

Appendix 9: Python code for seasonal time series prediction

Available on Github : PFE/Prediction model.py at main · raniayc/PFE (github.com)

Appendix 10: Pesticide use report

Pesticide Use Report

Date of Application: 10/06/2024

Prepared by: YAICI Rania

1. **Pesticide Details**

- **Type of Pesticide:** Insectides
- **Quantity Used:** 2L
- **Concentration:** 2g/ml

2. **Application Details**

- **Area of Application:** Zone sud-oued
- **Method of Application:** spray

Approval

Date: 24/06/2024

Appendix 11: Preventive measures Report

Report

This report outlines the findings of the recent risk assessment conducted at Dechetterie .The assessment aimed to recommend measures to mitigate the risk effectively.

Based on the identified risk level, we recommend that Preventive measures must take place:

- ✓ Install air curtain
- ✓ Use fine mesh screens to cover ducts
- ✓ Use appropriate sealants and gaskets to close gaps around pipes
- ✓ Use appropriate sealants and gaskets to close gaps around cables

The identified risk level in the storage room requires the implementation of the outlined measures to ensure a safe and pest-free environment. Continuous monitoring and adherence to the recommended practices will help mitigate future risks effectively.

Prepared by:

Yaici Rania

Yaiici.rania@gmail.come

24-Jun-24

Appendix 12: Compliance Review After implementing the actions

ID	Requirement	Compliance
General	How can we integrate an effective pest management system to enhance overall food safety and quality within our production facilities?	80%
	How is your pest control program documented to identify target pests?	100%
	Does the analysis effectively cover the common types of pests and animals, considering their presence in various environments?	100%
	To what extent does the design of the pest control program incorporate considerations of the external surrounding environment?	100%
	How effectively does the design of the pest control program assess local surrounding businesses to identify potential pest attractions?	80%
	To what extent does the developed pest control program address the effectiveness of pest management measures relative to the proximity to the point of manufacturing?	60%
	How effectively does the implemented pest control plan ensure that all chemicals and traps comply with local legislation and do not pose a risk to employees, products, or the environment?	100%
Pest Control Responsibilities	How effectively do operations contracting pest control services to a third-party ensure that the contractor possesses the necessary capabilities, training, and understanding to conduct pest control activities in food manufacturing facilities?	100%
	How regularly are audits conducted on the pest control program to verify its effectiveness?	100%
Preventing access	How consistently are buildings maintained in good repair, and are potential pest access points such as holes and drains adequately sealed?	60%

	How effectively are external doors, windows, and ventilation openings designed to minimize the potential for entry of pests?	60%
	Are all doorways appropriately sealed at ground level to prevent rodent entry?	60%
	How are frequently used doorways managed to prevent entry of birds and other pests?	80%
	Are suitable prevention devices used in areas where the potential for bird activity exists?	80%
	Are air curtains utilized on doors to processing areas as a deterrent to the entry of flying insects?	0%
Harborage and infestations	How are your storage practices designed to minimize the availability of food and water to pests?	80%
	Describe the processes included in your incoming material receiving program to inspect materials and shipping devices for pests.	100%
	How do you inspect incoming ingredients and package integrity for signs of pest infestation?	100%
	What procedures are in place to immediately isolate materials found to be contaminated with pests?	100%
	How do you manage materials found to be infested with pests, especially in terms of using or disposing of these materials?	60%
	What process is in place for inspecting pallets for pest activity before use within the facility?	100%

	How do you maintain the facility grounds to prevent areas of infestation?	60%
	Could you provide documentation that illustrates how your facility's waste storage, including the use of trash compactors and refuse containers, is managed to prevent pest attraction and harborage, and how these are maintained in a sanitary manner?	100%
	How your waste storage practices are designed to prevent pest attraction and harborage, including details on storage methods, frequency of waste removal, and staff training on these practices?	60%
	What measures are in place to avoid the build-up of old machine/equipment parts or building materials that could harbor pests?	0%
	How are areas within the facility where infestation may occur identified and included in routine inspection and pest control activities?	100%
Monitoring and detection	Can you provide detailed evidence of your pest-monitoring program, specifically regarding the placement of detectors and traps throughout the facility ?	80%
Eradication	What immediate eradication measures are implemented after evidence of pest infestation is reported, and how do these measures comply with local regulations?	100%
	How do you ensure clean-up activities from infestations, such as bird nests or droppings, prevent the spread of disease or contamination?	100%
	Can you demonstrate that pesticide use and application are restricted to trained operatives and controlled to avoid product safety hazards?	100%
	How are records of pesticide use maintained, detailing type, quantity, concentrations used, application details, and target pest?	100%
	Are exterior monitoring devices or bait stations for rats and mice tamper-resistant, anchored, and properly labeled?	80%

	What internal control programs are in place for pest management, and do they comply with legal and safety standards?	100%
	How are electric flying insectocutors placed to avoid attracting insects inside the plant and prevent contamination?	80%
Total		81%