# Information Technology and Data Analytics for Beekeeping and Beehive Health

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***Abstract*— The Apiculture (beekeeping) sector faces modern business challenges that require greater efficiency. The beekeeping community is confronted with its own technical and environmental issues in conjunction with regulatory and economic responsibilities. This study has conducted a New Zealand wide online survey among registered beekeepers and business. These individuals have varying levels of interest and investment in apiculture, as well as diverse viewpoints regarding the significance of digital beekeeping data and data management practices. Therefore, this study brings these together and synthesizes these information requirements for future information technology tools**

**The Research Question has been: What data is critical to hive health, and why? Consequently, the online survey results indicate that there are unmet data needs related to hive inspections. This includes data related to hive health and external factors. Hive health monitoring offers the most fertile area to deploy further digital technologies and help transform beekeeping business.**

**The three most important external factors identified by beekeepers that point to data needs are extreme weather, pesticide use and condition of nearby apiaries. These present opportunities for the development and implementation of innovative technology-based solutions. The conclusions discuss the opportunities exist for data storage related to geographic locations alongside floral, crop and natural vegetation density, as well as hive density.**

***Index Terms*— Digital Transformation, Information Technology for Beekeeping, Information Management.**

## I. Introduction

The introduction will explain the wider context including the Apiculture Sector and Information Technologies in the Apiculture Sector. The overall contribution of this study is a clearer understanding of the most efficient use of data captured in the apiculture industry critical for beehive health, the environment and best management practice. Factors including stakeholders, beehive health, practices and processes relating to apiculture data will be investigated to help beekeepers organise data efficiently and contribute to best practice.

Beekeeping enterprises are commonly classified according to their scale. Hobbyist beekeepers who maintain a small number of beehives, typically in a range between one and fifty, are often associated with backyard or urban beekeeping. In contrast, commercial beekeepers typically manage larger numbers of hives, with over 350 hives in the care of each enterprise. At the highest end of the spectrum are mega commercial operators, who manage a staggering number of hives, typically exceeding 3,000 for each one. Commercial beekeeping is a significant area for economic growth and technical development. This is particularly related to high-value products such as Mānuka honey, which is well-known for its anti-bacterial and anti-inflammatory effects.

In recent years, data availability, big data analytics, and connected technologies have seamlessly become a priority across many industries. Decision-making and economic advantage are improved through automation and data processing [1]. IoT platforms provide data-gathering solutions using sensor and cloud technologies, and devices are programmed to connect and exchange data. An inspirational digital beehive project was started in the USA in 2015 by Seidle [2], utilizing IoT sensors and Wi-Fi for remote beehive health monitoring. The system measured hive weight, humidity, and temperature, offering a technology alternative to manual hive inspection. The hive was positioned on a scale on a wind-shielded platform. Data from sensors was sent to the Internet in a raw beehive data stream and visualised using analog.io, a free open source software (FOSS) that can provide analytics for identifying trends and patterns in the data. This project ran until 2019 and involved Seidle (who is an Electronics Engineer, CEO of SparkFun and local Beekeeper interested in remote hive monitoring) and the open source programming community.

ApiTrak is a traceability software system that is used to track Mānuka honey from hive to consumer. This is especially important in New Zealand, because much of the Mānuka honey value is held by the Maori economy. The system uses near field communication radio frequency identification (NFC RFID) tags attached to hive equipment, mobile apps, and PC based platforms to collect data about the honey, which is then stored in a cloud-based database. This data can be accessed by stakeholders in the Mānuka honey industry, which helps to ensure the integrity of the honey supply chain [3].

In 2020, a project began under Apimondia (the International Beekeeping Federation) which governs beekeeping. This aims at the sharing of knowledge among beekeepers, academics, researchers, scientists, and industry experts [4]. The formation of the Apimondia BeeXML Working Group aimed to establish a standardised protocol for the exchange of data for beekeeping.

The goal of Apimondia's project is to pool efforts and work towards developing a universal data standard format that facilitates the exchange of diverse types of data related to beekeeping and honey production. Such data includes hive monitoring information, honey quality details and other relevant data. The BeeXML standard [5] proposed the idea of a beekeeping standard based on the fact that beekeepers around the world have widely accepted the Langstroth hive. This hive structure was designed to recognise the need for standardized “bee space”, sizing, frames, materials and equipment, in order to make it easier for beekeepers to scale and adapt apiaries. In summary, there are significant opportunities for the apiculture industry to draw on data, information, and technologies. With standards that have emerged in recent years, many benefits are yet to be explored in new studies such as this one.

Decisions of primary importance for beekeepers are associated with colony management [6]. The process of decision-making relates to the management of bee health and well-being, through the provision of a suitable hive environment that supports productivity. Factors such as ensuring ample honey stores and offering supplementary feeding during winter are also integral to the effective management of queen bees to mitigate complexities that could disrupt productivity. The status of each hive and apiary has a direct correlation to a range of decisions that beekeepers are required to undertake on a daily, weekly, monthly, seasonal and yearly basis. Several important decisions are linked to the availability and accessibility of bee forage and nutrition, bee breeding and genetics, bee product harvesting and processing, marketing and sales, regulatory compliance, financial management, and environmental stewardship. Making informed decisions requires adequate data collection.

Decisions may include how many hives to maintain, where to locate apiaries, which crops to focus on for pollination, and when to split or merge hives. Equally so, consideration must be given to a beekeeper’s requirement to employ and schedule employees, as well as allocate vehicles and equipment resources to operational tasks. Therefore, the accessibility and quality of resources, specifically information, in conjunction with effective management practices, are critical determinants of business performance, productivity and profitability.

Honeybees are susceptible to various environmental stressors which pose potential threats to their health and survival. These may include infestations of pests and diseases, harsh weather conditions, and inadequate nutrition. It is critical to make well-informed decisions regarding the appropriate timing and method of intervention in order to maintain the health of colonies. This may involve the selection of appropriate treatments for diseases, the timing of supplementary feeding, and the replacement of a failing queen. Therefore, recording this critical information serves to support the most accurate and timely decisions and actions related to hive health status.

Remote hive monitoring is designed to support many aspects of colony management and improve beekeeping practices in general. For example, monitoring weather and seeing variations such as warmer temperatures and increased humidity can help lead to swarming. Sensors that monitor weather parameters can be programmed to trigger alerts for a hive or apiary. This will help beekeepers predict when swarm conditions are likely to occur and take steps to prevent them.

Extreme weather and changing patterns can also have a detrimental impact on the availability of food and water for bees. Floods and drought conditions may lead to a shortage of nectar and pollen. Data technologies can help beekeepers monitor weather patterns in order to plan ahead and ensure that hives have enough food and water to survive. This is also important for migratory beekeeping where apiary sites are located in distant or remote areas. Cyclone Gabrielle is one example of an extreme weather event that took many people by surprise. Hive losses due to the cyclone were significant in the Hawke’s Bay plains [7]. The key differences between remotely monitoring weather using sensors and manual weather monitoring, is that the manual approach can be based on subjective, opinions and decisions that may influence a delay in timing a response, possibly due to being less accurate or human oversight. On the other hand, remote monitoring systems can collect data and output predictive alerts. Beekeepers can potentially initiate a hive rescue operation sooner with a high degree of accuracy.

The effective management of beekeeping enterprises relies on the capacity of beekeepers to make well-informed strategic decisions regarding their product offerings. The practice of beekeeping is subject to a multitude of risks, including environmental changes, disease outbreaks, and market fluctuations. Beekeepers have a responsibility to make decisions that will help mitigate these risks. Potential strategies include diversifying their products, investing in insurance, or integrating sustainable practices. Furthermore, the delivery of pollination services is an area in which beekeepers play a crucial role in maintaining ecological balance. Essential decisions relating to sustainable practices, such as reducing the use of chemicals, promoting biodiversity, and managing bees in a natural way, are crucial for the broader ecosystem.

Traditional beekeeping depends primarily on hive inspections for gathering invaluable information about hive health, productivity optimisation, and susceptibility to any potential issues. Typically, inspections are conducted manually, and at regular intervals depending on the season, requiring a labour-intensive and time-consuming process.

Accurate visual observations are essential to inspect for signs of disease or parasites, evaluate the brood pattern, observe the queen’s health and productivity, assess honey and pollen stores and monitor the overall strength of the colony. Beekeepers also need to ensure the hive has adequate ventilation and space for honeybees. Typically, inspections are recorded in a notebook or diary, documenting key information such as colony behaviour, disease occurrences, honey production and other relevant details. Differences in the personal preferences of beekeepers have led to the identification of alternative methods. These current manual approaches may include the use of checklists, whiteboards, stickers, or physical markers on the hive.

Beekeeping is a physically demanding occupation that necessitates frequent handling and relocation of the hive boxes. In [6], authors point out that “moving hives can be rather unpleasant, and without proper preparation the exercise can become very problematic". Beekeepers also need to wear cumbersome protective clothing when working outdoors, often, in a variety of weather conditions, and sometimes in challenging terrain. In some situations, the inspection may remain undocumented until the beekeeper has distanced themselves from the apiary. A timing delay means the beekeeper will need to depend on recollection of his/her observations made and subsequent actions to be taken. Improved decision-making is a key reason why some beekeepers have advanced from the traditional method of manually recording hive inspections. New methods include software, spreadsheets, mobile technologies and remote monitoring equipment. The next section explains the research methodology. This is followed by a literature review, which has revealed that published research on data analytics and data technologies specific to the apiculture industry is somewhat limited. The fourth section covers the empirical findings. The final two sections are the Discussion and Conclusions.

## II. Research Objectives and Methodology

The Research Question is: What data is critical to hive health, and why?

Hive health is the most important consideration in beekeeping, as it can have a calamitous impact on any operation. Information on hive health data is sourced from literature reviews, interviews, and an online bulletin board group. This primary research study started in 2022 and continued during 2023. This study employs a mixed methods approach to investigate critical apiculture data, with the aim to influence information management practice in the New Zealand beekeeping sector.

The methods in this study include collecting quantitative data by administering an online survey and collecting qualitative data from a bulletin board focus group sequentially to help the design later in this study. The greater diversity from collecting these two types of data will ultimately provide a more complete understanding of the affordances and limitations in the beekeeping industry and the role of data.

The participants in the online survey are a voluntary sample of registered beekeepers in New Zealand. These individuals have varying levels of interest and investment in apiculture, as well as diverse viewpoints regarding business management and data related practices. The general characteristics of this sample may be deemed representative of a cross-section of the New Zealand beekeeping community. The aim was to collect responses from a representative sample from this population, covering approximately 1 to 5% of the total number of beehives. The respondents in this study selected their specific location within New Zealand's sixteen regions and an appropriate category that identifies their level of interest and investment in beekeeping.

A stratified sampling method was employed to divide the sample population into two groups based on their shared characteristics. The two groups are identified as Professional and Hobbyist. The Professional group are beekeepers who operate in a business capacity, which includes side-line, commercial and mega-commercial beekeepers, while the Hobbyist group are beekeepers who are engaged primarily for recreational purposes. This allowed for more precise conclusions by ensuring that each subgroup is properly represented in the sample.

Survey respondents were asked in the online survey to provide their email contact should they wish to participate in a focus group. An online bulletin board focus group (BBFG) was selected as the method to further explore key topics introduced in the previous Survey. Padlet is an online interactive, collaborative tool selected for this focus group, due to being free, accessible, and widely used in education. Padlet allowed for the focus group questions to be organised as posts, colour coded into themes by topic, and further sub grouped into the specific question in the online survey. Results were downloaded from Padlet into Microsoft Excel for review. Sentiment Analysis was conducted with the Azure Machine Learning tool in Excel. This data mining into subjective information provided an opportunity to gain insights into the beekeeper's sentiment on topical questions and themes presented in the online bulletin board focus group.

The responses obtained through voluntary sampling are highly dependent on ease of access to the online survey, and, to some extent, biased to some degree due to the fact that some individuals will inherently be more likely to volunteer than others. Although potentially informative, the viewpoints expressed through the survey may be subject to bias, as the participants who contributed are more likely to have strong opinions regarding apiculture.

The initial expectation was to get 50-100 responses from a list of approximately 9,000 registered New Zealand beekeepers. Based on this initial online survey, the online bulletin board went on to investigate more specific areas. Focus group members included those who expressed an interest to be part of this process via during the online survey. A summary report from this study was also given to the representative of Apiculture New Zealand.

Information was gathered from beekeeping community participants about what data and type is recorded across different beekeeping enterprise categories. This encompasses hive inspections, seasonal hive management, regulatory functions, land owner relationships, education, technologies and other data requirements associated with bee services and products that support business stakeholder relationship processes.

The study begins with quantitative data collected from a broad survey of New Zealand registered beekeepers. The survey instrument contains multiple types of questions which work together in order to elicit useful and contextual responses.

The second phase focuses on qualitative responses using an online bulletin board. The qualitative about the expressed needs and experiences of beekeeping participants will augment and better describe the concepts in the quantitative surveys.

By sourcing feedback from a variety of stakeholders, the researcher can ensure deeper understanding of apiculture expertise and the knowledge of work processes, data relationships, and elements.

## III. Literature Review

The New Zealand beekeeping sector has experienced significant growth and development, driven by a strong global demand for honeybee products, increased awareness of the health benefits of honey and love for New Zealand's unique flora. However, unpredictable weather patterns, weather events, and climate change, have also affected bee populations, honey yields, and the availability of floral resources in several regions in New Zealand. Habitat loss is often attributed to activities such as deforestation, agricultural expansion, and urbanisation which leads to a reduction in the availability of forage for bees. The beekeeping industry has addressed these concerns by promoting sustainable land use and habitat restoration efforts [8], which require good planning based on quality information.

Emerging technologies rely on the availability of data, big data analytics, and connected technologies to solve problems. Decision-making can be less cumbersome when automation through data processing is involved [2]. IoT platforms are providing solutions using sensor and cloud technologies to exchange data with minimal intervention from humans.

Several studies have incorporated GIS with traditional database systems to help solve problems. GIS technology encompasses the management of database interfaces, spatial analysis and geoprocessing capabilities, and the creation of map and visualisation features. The creation of thematic maps is among the functions of a GIS and allows for the integration of spatial data (location) and attribute data (characteristics).

Although GIS has been widely studied in agriculture, a previous literature study found a paucity of research relating to GIS use in apiculture [9]. The previous literature review also elaborates on potential uses of GIS for beekeeping activities. Examples may include combining remote sensing (RS) with GIS and incorporating GIS with Multi-Criteria Evaluation (MCE) to identify apiary sites using satellite imagery to monitor the spread of a given plant species. These can help calculate a suitable number of hives per hectare to obtain optimum honey productivity levels. In another paper, GIS has actually been used to track contamination, map locations infested with specific diseases or pests, and foraging activity [10].

In [11], the researchers conducted a significant project that focused on the development of an interactive mapping tool based on GIS technology. The utilisation of GIS software proved to be a valuable resource in supporting beekeepers in various aspects of their work, as also noted in [10]. There were two critical themes [11]. Firstly, the presence of honeybees is paramount to the pollination of crops and therefore, crucial in maintaining the sustainability of the agriculture sector. Subsequent to this, it has been noted that beekeeping activities involving honey production and other bee products beyond pollination can provide economic and ecological benefits for rural development [11]. However, the achievement of these desired outcomes depends largely on effective beekeeping management and careful decision-making. The value derived from analysing data and its usefulness for the wider beekeeper audience both rely heavily on the specifics of data entered into the system and relevance of information outputs.

Equally so, [11] identified complexities involved in selecting optimal flowering and foraging locations for beehives, especially in the context of migratory beekeeping where criteria for flowering are time-dependent [12]. Time dependent dynamics of pollination success in different cultivars is complex. Likewise, another study [10] focused on the complexities and constraints involved in the selection of suitable apiary sites. This was achieved by integrating GIS along with multi-criteria evaluation (MCE) to map out individual cultivars in a generally wide region. The interactive flowering map application was driven by data from two primary sources, namely agricultural crop information and area locations. However, there was a lack of sufficient data about surrounding natural vegetation. Sometimes, the lack of internet coverage can pose a potential constraint on the scope of data collection, as well as any consequential analysis, which may then result in limited informational insights [11].

In some months of the year, weather conditions present challenges for many beekeepers who must brave the elements when conducting hive inspections [13]. The weather in many parts of the world, particularly during winter contribute to colony losses [14]. Increasingly, with climate change honeybees and beekeepers are bearing the impact of extreme weather that can damage bee habitat, limiting food sources or presenting other threats to honeybee health. A recent example is Cyclone Gabrielle that severely impacted the East Coast and other parts of New Zealand and devastated beekeepers [15].

Up-to-date weather reports ensure beekeepers can time hive movements and manage bees without unnecessary risk. Many use weather apps such as MetService for weather notifications, but sudden extreme weather events such as a cyclone leave little time to be prepared. This may be helped by technological advances such as remote hive monitoring, which is geared towards improving the hive inspection process and detecting colony health problems early on.

Another example of access to weather data is the WeatherMap application programming interface (API) used in [11]. The API was used to get data sets containing temperature, humidity, air pressure, and wind speed measures needed for the interactive mapping tool. The same API also provided air pollution data, important as pollution affects bees' scent detection of flowers and their foraging efficiency, plant pollination, and reproduction. The Shannon Diversity Index measures crop diversity and evenness [16]. It helps with mono-floral honey production and environmental sustainability. A higher index indicates greater plant species diversity.

IoT sensor devices embedded in hives can reduce the need to physically inspect in winter or during extreme weather events. Sensors can capture data from a range of internal and external parameters [17]. A three-year study [18] in collaboration with Bayer Bee Care [19] and Solutionbee [20] used a machine learning approach to estimate colony health. Data was sourced from sensors in hives to monitor temperature, measure hive weight and variations in weight. Environmental data such as air temperature, dew point temperature, rainfall, wind direction were sourced from weather station data. The study shows that sensor and inspection data can be mined to detect colony health problems early.

## IV. Findings

First, this section analyses the results from the Apiculture Data Survey discussed in the methodology section earlier. In this survey, a total of 37 questions, sectioned into five themes, were answered utilising a mix of response types. The five themes are: 1. Participant Characteristics, 2. Learning and Upskilling, 3. Hive Practices – Data Management and Recording, 4. External Influences - Notifications and Information Sharing, 5. Technology Uptake.

The 2022 Apiculture Monitoring report produced by MPI showed that the number of beekeeper enterprises was 9,954, and the total number of hives amounted to 726,452. The sample size for this study based on number of beekeeper types is close to 1% while the sample size based on number of hives is close to 3%. The sample size is indicative of the beekeepers' limited willingness and availability to do online surveys. Multiple channels were employed to encourage increased survey participation: requests through two publications of Apiculture New Zealand to subscription members, email contact with the 16 regional Beekeeping Clubs across New Zealand, publication in the Apiarist Advocate magazine. Some beekeeping club representatives made requests for printed copies to be filled out at Beekeeping Club meetings.

The mix of beekeeping type respondents, by number of hives, is very representative of the overall population within the context of the Research Questions. The sample mix of beekeeper types is slightly under-represented in the group having ≤5 beehives, whereas it is slightly over-represented in the group having >1000 beehives. Nonetheless, the broad distribution between Hobbyists with ≤5 beehives and their Professional counterparts with > 5 beehives is evident in both the population and sample data sets, where the ratios are 71:29 and 62:38, respectively.

TABLE I
SURVEY RESPONSES

| Size (hives) | Surveyed Businesses | Total Hives in the Category |
|---|---|---|
| 5 or less | 43 | 106 |
| *6 to 50* | 12 | 215 |
| *51 to 500* | 7 | 1,427 |
| *501 to 1,000* | 2 | 1,600 |
| *1,001 to 3,000* | 3 | 4,425 |
| >3,000 | 2 | 13,500 |
| Total | 69 | 21,273 |

Number and size of businesses that have participated.

The Apiculture Data Survey results have been collated and grouped into the planned five themes. The beekeeper type, as seen in Table 1 by the participants' sizes in hives, is similar to the hive count population across the country.

Hive inspection is an important area for automation and digitizing data to improve long-term information and knowledge management. Figure 1 and Figure 2 show how often beekeepers perform the inspection task in each season in a year.

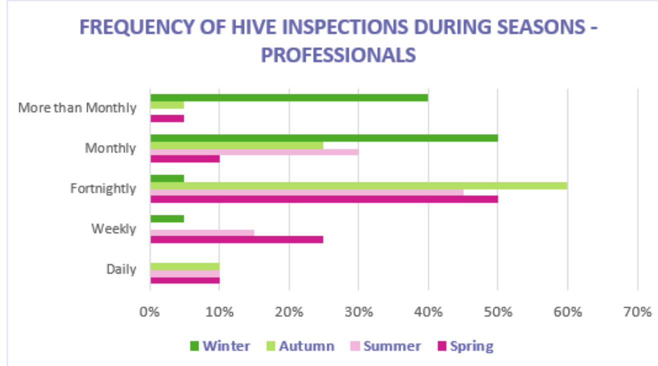


Fig. 1. How frequently professionals do the inspection task.

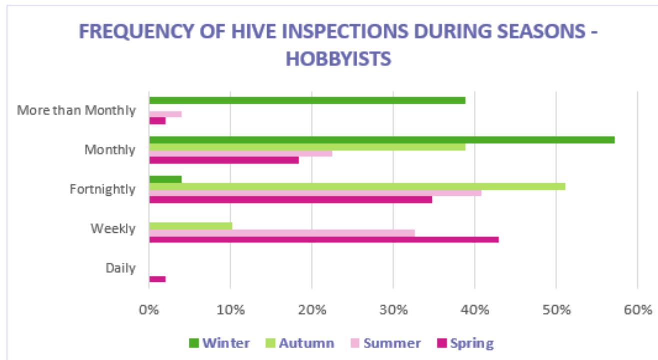


Fig. 2. How frequently hobbyists do the inspection task.

Figures 3 (professional beekeepers) and 4 (hobbyist beekeepers) below indicate what types of information are important for beekeepers and hive health. Knowing about these parameters is critical for setting up new information technology systems for beekeeping. Survey participants were asked what external hive information they record and how frequently. Fifteen external hive information parameters were given, which included (Beekeeper Registration #, Apiary location, Inspection date & time, Purpose of inspection, Weather, Temperature, Humidity, Hive repairs, Hive strength, Hive activity, Bees temper, # Brood boxes, # Honey supers, Hive weight, Bee count), and five frequency options ranging from "Always" to "Never." Participants were asked to select all the applicable choices from the options provided.

The results present each parameter and selections specific to the "Always" and "Often Recorded" frequency. This provides an indication of what external hive information parameters are most commonly recorded, mostly in a paper-based format. More than 50% of beekeepers, including both Professionals and Hobbyists, record the same five external hive inspections parameters as "Always" or "Often Recorded". These include: Inspection Date and Time, Purpose of Inspection, Hive Strength, Number of Brood Boxes, and Number of Supers.

A significant proportion of Professionals, specifically 95%, consider this information important due to operational scale, seasonal planning and distribution of hives across locations.

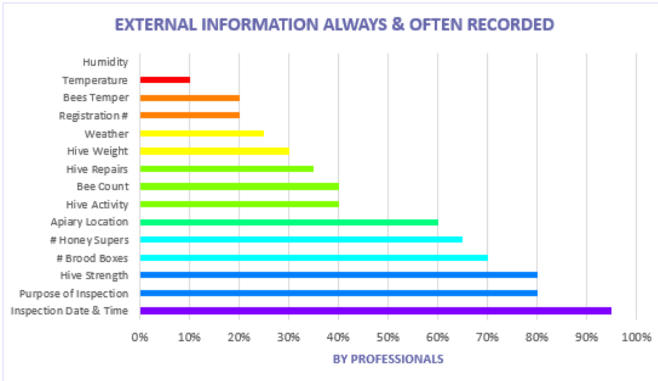


Fig. 3. External information recorded by professionals.

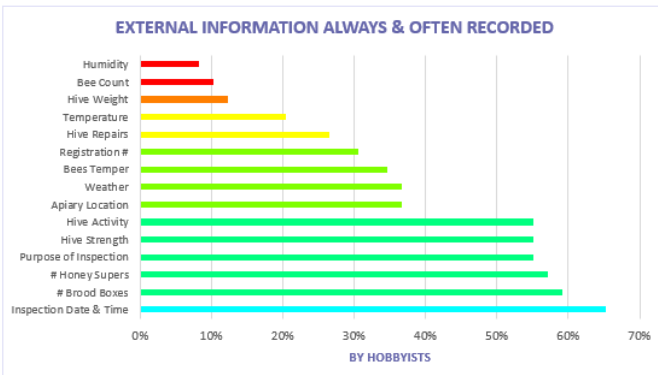


Fig. 4. External information recorded by hobbyists.

Results indicate that Purpose of Inspection and Hive Strength were the next two commonly recorded parameters among all beekeepers. As before, a significant proportion of Professionals, specifically 80%, record this information, while the proportion of Hobbyists reduced to 55%. Apiary location was identified as significant parameter by Professionals 60%.

Following the same pattern, it was observed that the subsequent two parameters, being Number of Brood Boxes, and Number of Supers, were most commonly recorded by Professionals and Hobbyists alike. Specifically, the recording of #Brood boxes and #Supers were prevalent among Professionals, with 70% and 65% of respondents recording the former and latter, respectively. Hobbyists recorded #Brood boxes and #Supers with a prevalence of 59% and 57%, respectively. This may be due to the ease of observation.

The remaining nine parameters were below 40% in terms of recording. This may be attributed to factors such as: lack of time, limited expertise, or inability to capture, merge and utilise the information effectively within current practice or routine.

As shown in Figures 5 and 6, participants were asked what internal hive information they record and how frequently. Sixteen internal hive information parameters were given, which included (Eggs seen, Queen sighted, #Stores honey frames, #Stores pollen frames, #Capped/Uncapped brood, Odour, Varroa count, AFB (American Foulbrood Disease), Chalk/Sac/PMS/Nosema, Wax moth, Dysentery, Treatment, Feed level, Syrup, Pollen, Note's to self or team), and five frequency options ranging from "Always" to "Never." Participants could select all the applicable choices.

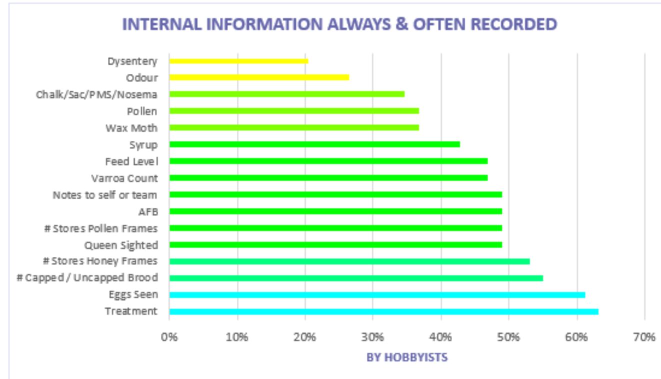


Fig. 5. Internal information recorded by hobbyists.

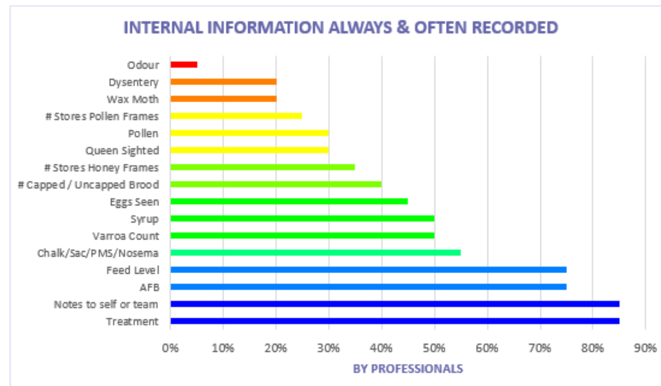


Fig. 6. Internal information recorded by professionals.

The results present each parameter and selections specific to the "Always" and "Often Recorded" frequency. The data has been split into the Professional and Hobbyist sub-segment. In contrast to the findings presented in the above section, it is notable that the internal hive inspection parameter "Treatment" has been recorded consistently as "Always" or "Often Recorded" by over 50% of both Professionals and Hobbyists.

A significant proportion of Professionals, specifically 85%, consider this information important, due to managing the magnitude and consequences associated with threats to honeybee health and productivity. While this parameter is also most commonly recorded among a slightly smaller proportion of Hobbyists, 64%, this is due to managing the threat.

The Hobbyist sub-segment indicated three additional parameters for internal hive inspection where over 50% of the respondents recorded these parameters as "Always" or "Often Recorded". These parameters are as follows: #Stores Honey Frames, # Capped/Uncapped brood, and Eggs Seen, possibly due to an emphasis on the strength and vitality of colonies.

The Professional sub-segment indicated a greater than 50% recording of "Always" or "Often Recorded" in four additional internal hive inspection parameters. These parameters are as follows: Chalk/Sac/PMS/Nosema, Feed level, AFB, and Notes to Self or Team, possibly due to prioritising the overall health and productivity of colonies.

As shown in Figure 7, survey participants were asked questions regarding the American Foulbrood (AFB) disease:

whether they receive notifications of AFB in their vicinity, whether they would be prepared to share their details to nearby beekeepers if they had their own AFB case, what would be of interest to them, to further understand if an AFB case was identified near their apiaries, and whether a video recording of AFB should be made by the inspector as proof if AFB is identified.

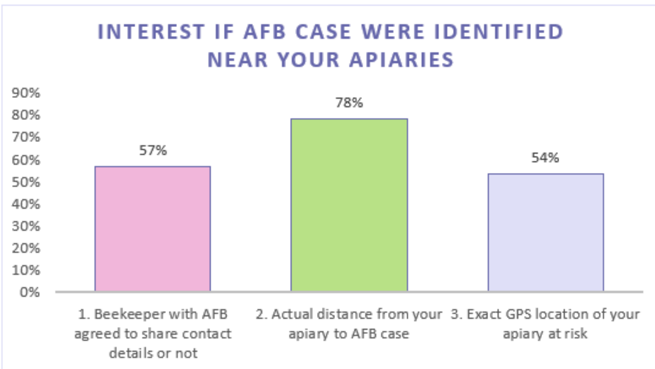


Figure 7. User interest in AFB notifications.

In terms of notification regarding AFB, the survey findings indicate that a majority, 84%, did receive notification regarding the presence of AFB in the vicinity of their hives.

When considering sharing personal details, it is important to restate that AFB, being one of the most contagious diseases that can affect an individual's hives, carries significant consequences for beekeepers. Not surprisingly, despite the perceptions of a fragmented industry, 80% of respondents agreed to share personal details in the event of their apiaries being infected with AFB. In terms of the three factors suggested of interest to beekeepers to gain further insights into any potential cases of AFB near their apiaries, distance was the most favoured with 78% of participants. When considering the Professional beekeeper sub-segment, this increased to 90%.

It was observed that 62% of beekeepers supported the idea of using video technology as evidence for the detection of AFB. This indicates a willingness amongst beekeepers to adopt alternative technology suggestions.

During the Bulletin Board Focus Group, one proposed recommendation also involved a feature for beekeepers to upload video to obtain analysis and/or a second opinion. An AFB video service may help with early detection and contribute towards clarifying the incidence of false positive tests. Video data from AFB inspections can be a rich source of information that can capture valuable insights for machine learning tasks.

The participants were asked about their understanding of forage and nectar availability surrounding their apiaries and how helpful it would be to get information on forage and nectar levels. The findings suggest that beekeepers need to possess a significant level of familiarity with their environment. A considerable majority of 82% of participants rated the vicinity surrounding their apiaries as "Somewhat Lush" or "Lush". Not one respondent perceived forage and nectar availability as "Somewhat bare" or "Bare". In terms of the desirability of receiving information about this aspect, only 39% of respondents indicated this would be "Somewhat helpful" or "Extremely helpful".

The lack of forage availability can be attributed to a variety of circumstances, often resulting from human activities, environmental changes, and natural factors. For example, too high a hive density can deplete the available floral reserves. A shortage of pollen and nectar availability leads to honeybees being undernourished which can result in weakened immune systems, reduced life span and decline in colony health. There are significant implications for beekeepers who need to be adaptive and resourceful in managing their colonies.

Beekeepers may need to provide food supplements such as sugar syrup or pollen substitutes. Although many do this, it begs the question "Are pollen and nectar sources available?" Other ways to conserve forage resources involves consolidating weaker colonies or perhaps relocating hives to areas with better forage availability. An opportunity exists for a data collection of geographic locations that relate to both floral, crop and natural vegetation density, as well as hive density.

During the Bulletin Board Focus Group, one proposed recommendation was for an app that connects beekeepers with the contact details of landowners that are willing to host hives and provide foraging details of their land. Another proposed recommendation was for an app that connects beekeepers with the contact details of landowners that are willing to host hives and provide foraging details of their land.

Overall, the survey results reveal the Hobbyist group, despite constituting a larger portion of beekeeping enterprises (80%), only manages a small fraction (2%) of the total registered hives. While the Professional group, representing a smaller portion of beekeeping enterprises (20%), is responsible for the overwhelming majority (98%) of the registered hives.

An opportunity exists for data collection of geographic locations related to floral, crop and natural vegetation density, as well as hive density. This can be a starting point for turning raw data into information for beekeepers and decision-makers.

The participants were asked questions regarding extreme weather patterns near their apiaries. Only 28% of respondents rated extreme weather patterns nearby their apiaries as either "Somewhat of a problem" or "Problematic". Despite this fact, 43% of survey participants advised that they receive information on weather patterns.

59% of participants indicated that receiving weather information in advance would be somewhat helpful or extremely helpful. The implication is that there is value in filling this data gap for the beekeepers.

Participants were asked questions regarding extreme weather patterns near their apiaries, as to what level of interest they have about the condition of nearby apiaries and how helpful it would be to get information on the condition of nearby apiaries.

A majority of the survey participants, accounting for 58%, were "Somewhat interested" or "Very interested" in understanding the condition of nearby apiaries. Not surprisingly, given the fragmented nature of the industry, 93% indicated they did not receive any up-to-date information on the condition of nearby apiaries. In summary, a majority of participants find this information helpful for management.

## V. Discussion

This Discussion section focuses specifically elaborates around the key Research Question shown in section 2.1.

Hive health is the most important consideration in beekeeping, as it can have such a calamitous impact on any operation. For this reason, data critical to hive health is highly important. Information on hive health data was gathered from the experts and the research and professional literature.

The online survey sent to beekeepers included two specific questions on what hive inspection information beekeepers record as either internal information or external information. Primarily taken into account was the percentage of survey respondents that "always" record and "often" record each of the listed parameters. It is assumed that any always/often parameter recorded by 50% or more of survey participants is important.

With regards hive health specifically, the online survey asked about four external information parameters that give an indirect indication of hive health. These are Bees Temper, Bee Count, Hive Activity and Hive Strength. In the case of internal information, a total of seven parameters relating to hive health are considered. These are Dysentery, Odour, Wax Moth, Chalk/Sac/PMS/Nosema, Varroa Count, AFB and Treatment.

Across these combined eleven parameters, the online survey results show that Treatment and Hive Strength are the two parameters that both Hobbyist and Professional beekeepers see as most important (>50% recorded as always/often). Professional beekeepers alone also consider AFB as important (Hobbyist beekeepers are just below 50% recorded as always/often) while Hobbyist beekeepers alone consider Hive Activity as important.

Parameters that either group see as less critical (<30% recorded as always/often) included Dysentery, Odour, Bee Temper, Bee Count and Wax Moth.

Finally, hive health is so important that 80% of online survey participants are agreeable to share personal details with regards to AFB infections. This is somewhat surprising because sharing such information may lead to regulatory risk or compromise competitive advantage. The willingness to share this personal information around AFB reinforces the importance of hive health to the beekeeping community.

The synthesis of the data that is critical to hive health is presented as an enhanced entity relationship diagram in Figure 8. The purpose of this is to visualize the data that needs to be scientifically incorporated into the future data dictionary and application databases.

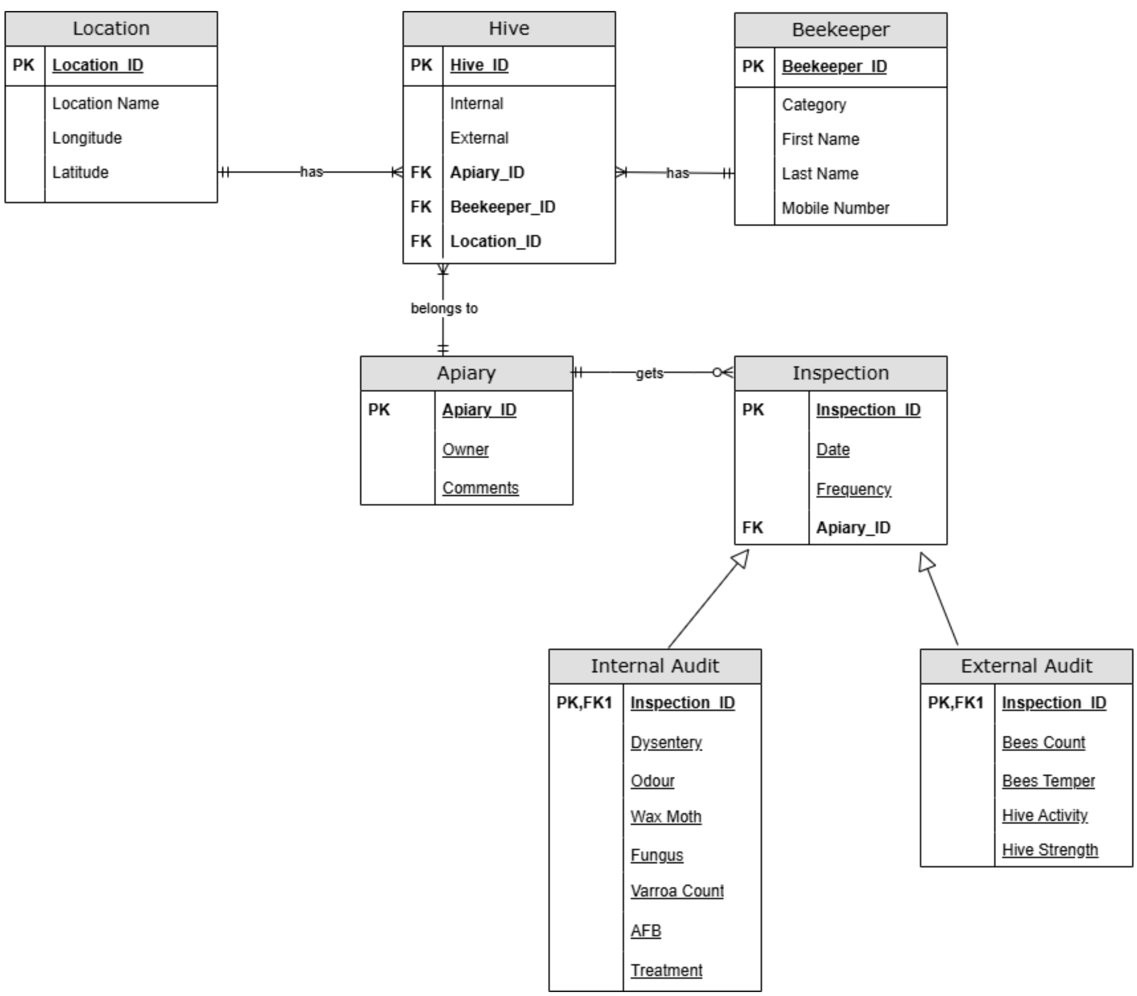


Figure 8. Summary diagram for hive data

An information science- oriented approach together with an appropriate database design will form the foundation of future systems and applications for beekeepers.

## VI. Conclusions

The online survey indicated that there were unmet data needs related to hive inspections. This included data related to hive health and external factors. Hive health is a major issue. For example, beekeepers will have to burn their hives if AFB is detected. Hive health monitoring offers the most fertile area to deploy further technologies. The three most important external factors identified by beekeepers were extreme weather, pesticide use and condition of nearby apiaries.

An opportunity exists for a data collection of geographic locations that relate to both floral, crop and natural vegetation density, as well as hive density. This can provide a starting point for turning raw data into information that can be useful for beekeeping stakeholders, for policy making, and for business decision-making, as in recent example projects in Ethiopia [23] and in Latvia [24].

The majority of beekeepers would consider video technology to help detect AFB, e.g. by using video data in machine learning and training models. The inspection process involves several brood observations that can indicate presence of AFB at various stages. Examples are: cell cap colour, sunken or holes in capping, spotty brood, colour of brood, and position of brood in a cell. All of these observations can be captured on video.

Machine learning models can be trained to support AFB detection by identifying anomalies or unusual events. Videos can be used to recognise phenomena within video frames, such as the matchstick test for 'ropiness'. Videos can be annotated to label and track objects, classified into different categories based on their content. Another recommendation is to establish a repository of AFB video recordings. Although video data would require significant pre-processing and technology considerations, this initiative would support the honeybees and also engage beekeepers, while raising the profile of machine learning and data driven technologies in apiculture.

A recent concrete example of an IoT project for beekeeping is being implemented in two provinces in South Africa [25]. Implementing new technologies will also present practical challenges, such as costs, beekeeper training, and accessibility. Future papers are advised to expand apiary databases to also incorporate binary object fields to store various multimedia files. These features will lead to interactive, educationally beneficial, and highly informative systems and applications for both commercial and hobbyist beekeepers in coming years.

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