

Case studies: field testing and user-friendliness of commercially available hive monitoring devices

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Introduction

A growing number of companies offer "smart-hive" devices in the form of sensors connected via Bluetooth, wifi or mobile network to the "Internet of Things" (IoT). These devices help sense various parameters within hives and their environment, commonly including humidity, temperature and weight. While the development of sensors, their electronic circuitry and software has received ample attention, little evaluation of their practicality, user-friendliness and precision has occurred to date. Beekeepers thus lack the opportunity to make informed choices when deciding whether to equip hives or select one system over another.



Figure 1. Sensors used to monitor hive weight, activity, humidity, and temperature, available on the market from various brands (e.g. Hivemonitoring, Hive IQ, Broodminder).

Here, we obtained commercially available systems from Australia, Europe and the USA. We equipped hives at Macquarie University with sensor systems from four hive sensor companies and lab-grade temperature sensors and scales. We ordered hive sensors from Broodminder (USA, France), ApisAus (Australia), BeeStar (Australia) and BeeHiveMonitoring (Slovakia). One additional company, BeeHero (Israel, USA) did not reply to multiple attempts to acquire sensors for testing or obtaining information. Two other companies were identified after testing was completed: HiveIQ (Australia), and BeeRight (Australia) and provided information regarding their systems.

We evaluated the systems from the first order to the general use of these systems over a few weeks in the field. We took notes on the ordering, delivery, installation, user-friendliness (including handling, app usage), client support (if needed), data fidelity and connectivity. We initially conducted a field trial over winter with the four systems, and renewed this trial once over the following summer for the two systems we considered most suitable for use by commercial beekeepers.

Field trial 1: initial "Winter" case study (Broodminder, ApisAus, BeeStar, BeeHiveMonitoring)

Case study 1: Broodminder

1) Ordering and Delivery

The total time from quote request to full delivery, excluding delays due to our own university processes, was 18 days. Broodminder was very helpful with our order. Ordering is clear and simple and can be done directly via the website or via resellers in Australia (on this date, The Urban BeeHive, Sydney, is the only identified local reseller). Due to the large size of our order and to satisfy requirements from the university, we contacted BroodMinder directly to obtain a quote. Broodminder was contacted on November 26, and we received quotes two days later. We placed our order on Jan 23rd due to the university's delays in ordering expensive equipment and because of the end of the year shutdown of services. The order was delivered 9 days later. A small part of the order was missing, and we contacted the seller who immediately sent the missing items on expedited international delivery, these were received 8 days later.

2) Installation

We ordered 8 BeeDar, 1 GSM cell, 1 solar shield for the cell, 16 internal T2SM hive monitor (temperature), 8 W3 scales partially assembled, calibrated, fixed feet, and 1 BroodMinder SubHub. The installation was simple, although manually assigning many sensor IDs to the app was tedious. This process must only be done once however and was time consuming in part because we ordered 2 temperature sensors, a BeeDar and scales for each hive. It is unlikely that commercial beekeepers would order all these sensors for each of their hives, so the task would be less time consuming. The app was easy to find and install, and data can also be accessed on a computer via the BroodMinder's website. The installation of the cell in the solar shield was simple. The scales were mounted onto wooden frames and the electronic box had to be manually opened to note the device identification number and activate the batteries, which was relatively time consuming. BroodMinder offers another type of scales (BroodMinder-W) that are assembled and may be more adapted to commercial beekeeping, it appears that the ones we chose are more targeted at researchers or hobbyists. BeeDars and temperature and humidity sensors were very easy to install and link to the app.

3) User friendliness

a. Sensor handling

Sensors were easy to handle and maintain. The temperature sensors come with a plastic attachment poking out of the hive that allows the user to check the device ID and the correct placement of the sensor without opening the hive. The sensors fit under a queen excluder without creating gaps with super boxes. The scales we chose were more difficult to maintain, feet were small and slippery, sometimes falling off the other scales they were mounted on, although this was specific to our experimental conditions were multiple scales were piled on top of each other to evaluate their relative precision. On a day with an unusually high amount of rain (about 120mm in 24h), water dripped down the cables leading the scale feet to the electronic unit despite the presence of joints and water proofing on the electronic boxes. Again, our choice of scales would have likely been best suited for research use or for hobbyists and BroodMinder offers an alternative that is likely better suited for commercial beekeepers (BroodMinder-W), which we realized after starting our trials. BroodMinder would likely recommend the other scales if they were contacted by a commercial beekeeper and not a university. These alternative scales do not have exposed cables.

b. App

Both the BroodMinder app and the website are easy to navigate. BroodMinder improved their app during our trial. The app allows to list all devices or all hives, offering multiple simple ways to access data and troubleshoot sensors. It includes a view by apiary for users with multiple apiaries. Navigation is easy and convenient. Within the Hives menu, a green-orange-red light system is displayed to quickly inform the user about the health of each hive. Tabs can then be easily located and access to obtain raw data relative to all the different sensors. One tab offers an estimation of the percentage of brood in the hives. The app allows the user to add notes about maintenance events. It was sometimes unclear why we could not access data from humidity sensors and BeeDars and the difference between the weight and the productivity tab was also unclear. The app has 2.9 stars rating on google play (26/09/2024, 17 reviews) although this might reflect ratings of the app before the major update, and a 5/5 stars rating on the apple store (26/09/2024, 5 reviews), which seems to reflect ratings of the app since the update.

4) Support

BroodMinder offers clear online documentation for each of their products, including videos. Support is easily accessible through the website or by email, and BroodMinder promptly responds to requests for support. Support was contacted to troubleshoot scale calibration, and offered clear explanations on how to check and recalibrate scales. Support was also contacted to download all data and offered clear explanations for this too.

5) Data fidelity

We are currently investigating data fidelity; early analyses suggest that the temperature data are very reliable.

6) Connectivity

Data was sent to the app via the cell with no other issues than outages from network providers. Communication with each individual Bluetooth device was sometimes more difficult, with some of the devices intermittently not sending data or refusing to connect to the app. Overall no significant data losses or access issues were observed.

Overall, we consider that this system is adapted for beekeeping operations within areas of cellular network reception. In particular, the simplicity of the app and the reliable temperature measurements will appeal to commercial beekeepers. We consider that the model of

the scale we assessed was not relevant to commercial beekeepers and we cannot formulate recommendations towards more appropriate models like the BroodMinder-W which we did not assess.

Case study 2: BeeHiveMonitoring

1) Ordering and Delivery

BeeHiveMonitoring was contacted to obtain a quote, which was received on the same day. Further communication was necessary to proceed with the purchase, and the company declined to communicate via emails, referring us to their online chat which seemed only accessible during European working hours (about 8 hours behind Australian Standard Eastern Time). The order was placed in on the same day. Once payment was processed by the university, the equipment was received 27 days later. In total time from order to delivery was 29 days.

2) Installation

Installation was generally difficult. A sim card had to be inserted in a gateway. Accessing the sim card slot is difficult as multiple extremely small hex screws must be carefully removed to open the gateway. We then had to contact support on the chat to configure the gateway, and it required obtaining an APN (later identified as being an Access Point Name) from Telstra. The company ignored requests for guidance on how to find the APN. Although Telstra provides clear guidance, it was initially difficult to identify what an APN was and how to enter this information. Support performed some remote operations to validate the change in settings although this required multiple restarting of the app and took about 2h after normal AEST working hours due to the time difference with Europe. It is unclear what was done by the company during this time to validate the new settings.

Device installation was simple for the temperature and humidity sensors ("Hive Heart") which were simply placed on top of the brood box, although these are rather thick and prevent perfect fitting of suppers when a queen excluder is in place. This may defeat the purpose of highly insulated hives that are becoming popular among beekeepers. Scales were relatively simple to install, but front and back load scales are connected to a box in the middle with cables. The box resembles other boxes for other sensors equipped with solar panels but does not seem to have a solar panel. Any cables complicate beekeeping operations as they may get caught in other elements during transport, get damaged, or prevent the clearing of debris that accumulate under hives equipped with ventilated floors. Bee counters were impractical, didn't fit our polystyrene hives, we could not find any attachment holes to maintain them in front of the hives and it was unclear whether there was a particular orientation for these sensors or not. These may have been designed for hives with a larger landing board, which are often not used for migratory (pollination) beekeeping. The cable linking the solar panel to the bee counter is awkwardly short and it is difficult to place the solar panel anywhere else than on the ground.

3) User friendliness

a. Sensor handling

The handling of the temperature and humidity sensor is relatively easy although it is too thick to fit under some lids and queen excluders. Scales fit well under the hives and are stable but are linked to a box with cables, although the cables seem relatively thick and reliable. Bee counters were very impractical, hard to fit and bees often found ways to go around them both on our polystyrene hives (HiveIQ, ACT, Australia) and in our wooden boxes (Hornsby Beekeeping, NSW, Australia).

b. App

The system comes with three apps, one seemingly aimed at troubleshooting equipment, one to access equipment locally via Bluetooth and one to access data sent online via the cellular network. This is a very confusing system. Apps are slow at displaying data, and difficult to navigate, which is reflected by a very low google play rating of 2.1/5 starts (26/09/2024, 104 reviews).

4) Support

Support was difficult to access. The Help page on the app appeared to link to a broken page. The pictogram manual provided is unclear and a few videos are available online but they did not provide the information I was searching for. Most requests for support via email were unanswered. Contacting the company via their chat was difficult, it had to be done on the phone to be close to the sensors deployed in the field while also navigating through the apps. Support could only be accessed during European working hours. Requests for information by email and via the website's chat service on how to download the data via the chat were left unanswered (conversations still appeared unanswered after several days including European working days and hours) and so data could not be evaluated against our own sensors.

5) Data fidelity

We could not identify how to download data from the app. The company did not reply to requests for information or data access. Data fidelity could thus not be directly evaluated. After removing all sensors from the

hives, hives "status", "bees", "queen" and "swarming" remained green, suggesting that the data were interpreted as coming from healthy colonies despite not being inside bee colonies. Scales without a load showed values ranging from -13 to +3 kg.

6) Connectivity

Other than issues with setting up the sim card mentioned above, no connectivity issues other than those due to outages of the network provider were observed.

Overall, we do not recommend Australian beekeepers use this system due to issues in accessing support, obtaining raw data, and setting up a functional array of sensors.

Case study 3: BeeStar (LB AgTech)

1) Ordering and Delivery

BeeStar from LB AgTech was contacted to obtain a quote before the company's official product launch. The company replied within a day and offered to meet a few days later to present their product and R&D projects. The company being in a prototyping stage at the time required additional time to prepare an invoice and dispatch the equipment, so reporting on the time it took to receive a quote and the equipment does not represent what beekeepers will experience now that the product is on the market. The BeeStar team was nonetheless prompt at replying and the ordering and delivery was overall a smooth and process. Sensors were delivered in person by a member of the BeeStar team.

2) Installation

The installation was simple. A satellite communications unit ready to operate simply had to be placed on a pole near the hives. Two gateways were placed easily between the lid and the box of hives and can alternatively be attached to any support nearby and are weatherproof. The sensors hang easily between the frames at the center of the hive, they will initially press onto wax comb and may result in minor damage to honey or brood cells. Bees quickly fixed the comb in our hives, leaving a small gap where the sensor can easily fit again when hives are opened. Overall the installation process was very convenient.

3) User friendliness

a. Sensor handling

Sensor handling was easy and convenient, the temperature and humidity sensor is rugged and simply hangs in between two frames. It is a bit too thick to be directly inserted between frames from the top, so the best way to place it back in a hive is to remove a frame from the hive, and slide the frame onto the sensor. LBagtech did not commercialise hive scales at the time of our order.

b. App

BeeStar provided access to a temporary app while finishing the development of their future app. This app was convenient and allowed to check the temperature and humidity inside the hives with simple figures, and their location. The app is likely to change in late 2024.

4) Support

Support from BeeStar was excellent. The company provides regular email updates, and alerted me once when they detected an abnormal temperature in hives that indeed had low population. The company also detected an issue with the satellite gateway which they replaced promptly.

5) Data fidelity

We are currently investigating data fidelity, but early results suggest that the temperature measurements are highly accurate. The location of the hives was accurate with a few meters of the actual location of the hives.

6) Connectivity

We experienced no connectivity issues. BeeStar provided us with both phone network and satellite connection options.

Overall, sensors from BeeStar are simple and easy to use and suitable for commercial beekeeping use. This system can be linked to a satellite device (which we have not tested in an area outside of cellular network so far) which may offer a reliable solution for the monitoring of hives in very remote locations. The company indicated they recently obtained certification by the National Farm Data Code and were actively working on developing their products further.

Case study 4: ApisAus

1) Ordering and Delivery

We asked ApisAus for a formal quote to equip 3 hives after an initial brief request to estimate the price of their system. ApisAus offered to provide 4 temperature and humidity sensors and a custom double microphone system to analyse sound changes within hives and sound differences with their environment. The system also included an accelerometer which sends automatic email

alerts when hives are moved. The quote was received within five days. ApisAus provides custom build hive sensor systems, which were built within 24 days after payment and delivered within 4 days after they were built. ApisAus delivered the sensors in person.

2) *Installation*

ApisAus installed the sensors. These were temperature, humidity and sound sensors. Sensors are connected via cable to a logger placed in a box with a mesh bottom under the lid, ApisAus provided boxes fit to our hives' dimensions (standard Langstroth 8 frames and HiveIQ high-insulation 9 frames). The sensors, connected to the central unit with a cable, hang between the middle frames. The sensor won't fit through the frames from the top in a full, tight box but one frame can be removed and slid back into place after placing the sensor in the hive. The data logger is also connected to solar panels that can be placed on top of the hive or nearby.

3) *User friendliness*

a. Sensor handling

Sensors are relatively easy to handle, the long cables allowed for ample maneuverability although cables do get in the way of common beekeeping operations. Easy access to the data logger in a box separated from the bees with a mesh allows to check that sensors are operating correctly thanks to a color code, and placed correctly in the hive. Solar panels can be easily disconnected and reconnected when opening hives.

b. App

ApisAus products targets beekeepers and researchers interested in custom solutions or research and development and provides users with raw data using an independent platform called ThingSpeak. ThingSpeak is an open source software to connect internet enabled devices such as sensors. Audio files were directly collected by the company on their private server which allowed direct download from a browser.

4) *Support*

Support from ApisAus was excellent, with the company sending regular updates and notifying us when they detected hives with potential health issues. The company monitored the systems' connectivity on a regular basis and detected one issue, after which they immediately came to replace the defective component.

5) *Data fidelity*

We are currently investigating data fidelity.

6) *Connectivity*

Connectivity was provided via a PocketWifi with a 4G Telstra sim card plugged into main power from a nearby building, ApisAus also mentioned solar power could be used if necessary.

Overall, ApisAus provided a high-resolution system with fast delivery and great personalized support. Currently, sensors are produced at small scale by ApisAus. This means that they are likely best suited for hobbyist beekeepers, bee researchers, or commercial beekeepers with high-value colonies (for example, colonies holding high value queens), or commercial beekeepers wishing to get involved in R&D or are interested in obtaining sound information from their bee colonies (for queen rearing for example). ApisAus has communicated their intention to scale up the production of sensors with real-time analytics eventually, which would make their sensors more suitable for general commercial beekeeping.

Field trial 2: second "Summer" case study (update on BroodMinder, BeeStar)

Case study Summer update: Broodminder

Following our first trial, we determined that the broodminder BeeDar and DIY scales had low relevance to the pollination industry due to the complexity of use, short battery life and high labour required to replace batteries, and fragility of the systems not compatible with commercial beekeeping practices. We decided to not renew the testing of these products and to order instead two BroodMinder-W scales that are more rugged for testing. We reused the temperature and humidity sensors from the first trial.

1) *Sensor durability*

Temperature and humidity sensors were found to be durable and resisted mild compression from the queen excluders. Batteries have now lasted over a year for these sensors and still show >90% full on the app, indicating the product is rugged and does not require frequent maintenance. Plastic holder strips have however broken down during hive movement and due to weather, and we recommend writing custom hive numbers with a sharpie directly on the sensor case to avoid losing the sensor ID in case it is reassigned.

The W scale is a half scale placed at the back of the hive, so that the front of the hive rests on the hive stand or pallet and the back on the scale. The scales were found to be durable with no signs of corrosion after 6 months, and batteries still showing 100% charge (although due to

the nature of standard AAA batteries, charge tends to drop faster at the end of their life).

The gateway is durable and shows no signs of corrosion, the battery had to be charged once during the summer and still shows 80% charge after 4 months.

2) *Sensor accuracy*

Sensor accuracy is high for scales, showing a clear daily weight change pattern as well as nectar flows and is sufficient to estimate when supers are ready to harvest. Humidity and temperature sensor accuracy is excellent, with no indications of lowering data quality over time. There are no indications that the humidity sensor was sealed up with propolis.

3) *General use*

The phone app was updated during the trial. The interface is complex and rather impractical, with some of the metrics unclear ("Productivity" for example is given without formula). Crucially, the app lacks a pop-up notification feature for ending subscriptions or low batteries which have caused us to loose data after the subscription ended, and when the gateway ran out of battery. Beekeepers using this system should set up regular reminders to check battery life and to auto-renew subscriptions.

Notifications showed up on the app that firmware updates were available for our sensors, although most updates failed for nearly all sensors even when leaving the Bluetooth connection active for over 30mins, after taking the sensors out of the hives. It is unclear why this occurred and we were not able to remedy this, but although this was frustrating and occasioned significant loss of time (over 10h to attempt to upgrade firmware), it did not block data collection.

The W scale was compact and convenient, with no cables getting in the way and good battery life. The temperature and humidity sensors are easy to use. Queen excluders or frames with burr comb might press on the sensors although we have not find this to damage the sensors in our standard langstroth wooden hives or in our HiveIQ polystyrene hives.

Case study Summer update: BeeStar

1) *Sensor durability*

BeeStar sensors are very rugged, no sensor damage have been observed in the last year. All batteries still have power. BeeStar is on top of their sensors' health, regularly checking in when they detect unusual data and offering replacement ahead of any potential issues.

2) *Sensor accuracy*

Sensor accuracy is excellent for temperature. "Flat lines" for humidity measurements were observed in a few hives, indicating that the bees likely covered the sensor with propolis which smoothens the humidity measurements or blocks them. Temperature measurement quality remained unchanged, and is the most important metric for beekeepers in this case.

3) *General use*

The use of the BeeStar sensors is very simple and convenient. Like in the first trial, we had no issues using this sensor, and the company regularly checked in to verify that the system functioned correctly. The company has put in place an automatic daily update system with a color code representing hive health, that can be received by emails. The app (we still use the INCYT manufacturer app while we wait for BeeStar to release their own app, which they indicate should happen in the next few months) is simple and shows a list of the hives with the raw temperature and humidity data.

Other systems on the Australian market (not tested)

HiveIQ (Australia) is a company producing high-insulation polystyrene hives. They provide a mobile network gateway and a T-shaped sensor box housing a humidity and a temperature sensor. HiveIQ hives are equipped with NFC to quickly connect hives to the app. They are currently trialing an algorithm to detect hives in need of attention (red-light/green-light system) and estimate bee and brood amounts within hives.

BeeRight (Australia) is a company commercialising hive sensors, including temperature, humidity and sound with an automated AI-based system to detect health issues and hive productivity.