International Partnership on Innovation

SAMS - Smart Apiculture Management Services

Deliverable N°4.4

Concept of the Decision Support System

WP 4 Decision Support System

Horizon 2020 (H2020-ICT-39-2017)

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SAMS consortium partners

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List of Abbreviations

CCD	Colony Collapse Disorder
DSS	Decision Support System
DW	data warehouse
ES	expert system
ICT	Information and Communications Technology
ITAPIC	ERA-Net ICT-Agri project "Application of Information Technologies in Precision Apiculture"
PB	precision beekeeping
UCD	user centered design
UI	user interface

Summary of the project

SAMS is a service offer for beekeepers that allows active monitoring and remote sensing of bee colonies by an appropriate and adapted ICT solution. This system supports the beekeeper in ensuring bee health and bee productivity, since bees play a key role in the preservation of our ecosystem, the global fight against hunger and in ensuring our existence. The high potentials to foster sustainable development in different sectors of the partner regions are they are often used inefficient.

Three continents - three scenarios

(1) In Europe, consumption and trading of honey products are increasing whereas the production is stagnating. Beside honey production, pollination services are less developed. Nevertheless, within the EU 35% of human food consumption depend directly or indirectly on pollination activities.

(2) In Ethiopia, beekeepers have a limited access to modern beehive equipment and bee management systems. Due to these constraints, the apicultural sector is far behind his potential.

(3) The apiculture sector in Indonesia is developing slowly and beekeeping is not a priority in the governmental program. These aspects lead to a low beekeeper rate, a low rate of professional processing of bee products, support and marketing and a lack of professional interconnection with bee products processing companies.

Based on the User Centered Design the core activities of SAMS include the development of marketable SAMS Business Services, the adaption of a hive monitoring system for local needs and usability as well as the adaption of a Decision Support System (DSS) based on an open source system. As a key factor of success SAMS uses a multi stakeholder approach on an international and national level to foster the involvement and active participation of beekeepers and all relevant stakeholders along the whole value chain of bees.

The aim of SAMS is to:

- enhance international cooperation of ICT and sustainable agriculture between EU and developing countries in pursuit of the EU commitment to the UN Sustainable Development Goal (SDG N°2) “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”
- increases production of bee products
- creates jobs (particularly youths/ women)
- triggers investments and establishes knowledge exchange through networks.

Project objectives

The overall objective of SAMS is to strengthen international cooperation of the EU with developing countries in ICT, concentrating on the field of sustainable agriculture as a vehicle for rural areas. The SAMS Project aims to develop and refine an open source remote sensing technology and user interaction interface to support small-hold beekeepers in managing and monitoring the health and productivity in their own bee colonies. Highlighted will be especially the production of bee products and the strengthening of resilience to environmental factors.

- Specific objectives to achieve the aim:
- Addressing requirements of communities and stakeholder
- Adapted monitoring and support technology
- Bee related partnership and cooperation
- International and interregional knowledge and technology transfer
- Training and behavioural response
- Implementation SAMS Business cooperation

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Executive summary

The following report provides, first of all, important background information on (1) definitions of a Decision Support System (DSS); (2) precision agriculture; (3) DSS application in beekeeping; (4) the actual concept of decision-making and (5) its possibilities of how to describe/ set up such DSS, to understand the concept of the DSS developed within the SAMS project better. In the SAMS case, a DSS is a computer-based system, which is used for automatic data analysis for decision support of the beekeeper with the main aim to recognize the status of the monitored object – the bee colonies.

To assess the status of a honeybee colony, the beekeeper needs to visually (physically) inspect the colony. This procedure is time consuming and raise additional stress to the colony. The continuous and remote monitoring of the bee colonies by appropriate ICT solutions (precision beekeeping) may be a useful tool to support the management of honeybee health, colony development and even bee productivity.

It is not possible to get added value from different bee colony measurement systems without sufficient data analysis. A DSS can be adapted for the precision beekeeping for automatic data analysis and is considered as one of the sub-systems of the precision beekeeping using different algorithms and models, based on generated data from the respective hives. The DSS shall help to automatically identify different bee colony states, warn the beekeeper if abnormal situations occur within colony and provide him with further information, which activities are necessary to ensure the health of their colonies and to practice an efficient beekeeping. The DSS can help the beekeepers to identify different bee colony states. Different bee colony states may have different levels of importance and can be identified with different levels of reliability.

The DSS can process and combine data related to the bee colony weight, temperature, sound etc. Decisions of the DSS can be split into two groups: individual rules, which are based on single colony monitoring and differential rules, which are based on comparison of different colonies within one apiary. The possible individual bee colony states that could be identified include:

- mass nectar flow,
- absconding,
- broodless,
- death,
- swarming.

The description of possible bee colony states and needed actions are summarised in the SAMSwiki. The SAMSwiki is a free open-source knowledge hub aiming to collect beekeeping expertise from around the globe. Links to the wiki platform are also provided by the SAMS data warehouse (DW) (more details can be found in D4.1 Report on Data Management), which is an universal system that can operate with different data inputs, process data using flexible algorithms and provide appropriate output. The DSS, described in in the following report, is also an integrated part of the SAMS DW.

1. DSS definition and architecture

When looking at the definition of a Decision Support System (DSS), it can be concluded that there is not one specific definition for it. According to literature[1], there are as many DSS definitions as one could find articles/ literature about this topic. The claim is also supported by other source[2] emphasizing the fact that the number of definitions is growing alongside the number of authors/ researchers that are interested in this field. As a result, this wide range of definitions causes confusion about the basic concepts of a DSS. The reason for that is given as follows[3] – it is not possible to define a DSS precisely, by including all aspects of it, because aspects are individual and context, as well as domain, specific, but a common fact of all definitions and considerations for a DSS is that it includes the aspect of a decision--making process.

In general, a DSS can be defined as any system that assists in any kind of decision-making process[4]. A decision is a choice between many options, including “do nothing”.

It should be mentioned that a very similar term to DSS is expert system (ES). The biggest difference is that ES imitates the knowledge of a human expert and completely (or at least partially) replaces the human-decision maker – it can operate at the expert’s level (e.g., determining medical diagnosis[3], diagnosis of honey bee diseases, pests, parasites[5]). Although, there are sources that use these terms interchangeably.

Some of the main characteristics that describe a DSS[1,6] are:

- is intended to support the decision makers, but not to replace them;
- focus is on the effectiveness of the decision-making process, not on the efficiency of the DSS;
- is controlled by the user;
- uses data and models as its basis;
- is interactive and user-friendly.

In overall the DSS architecture consists of five components (see Figure 1):

- data management system – intended for data retrieving, storing and organizing;

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[1] Marakas, G. M. (2003). Decision support systems in the 21st century (Vol. 134). Prentice Hall Upper Saddle River, NJ.
[2] Nižetić, I., Fertalj, K., Milašinović, B. (2007). An overview of decision support system concepts. In 18th International Conference on Information and Intelligent Systems (pp.251–256).
[3] Gebus, S., Technica, C. (2006). Knowledge-based decision support systems for production optimization and quality improvement in the electronics industry.
[4] Bruen, M. (2006). Introduction to decision support systems. In River basin modelling for flood risk mitigation (pp. 235–248). London: Taylor & Francis.
[5] McClure, J. E., Tomasko, M., & Collison, C. H. (1993). BEE AWARE, an expert system for honey bee diseases, parasites, pests and predators. Computers and electronics in agriculture, 9(2), 111-122
[6] Power, D. J., Sharda, R. (2009). Decision Support Systems. In Springer Handbook of Automation (pp. 1539–1548). Springer.

- model management system – performs data retrieving, storing and organizing needed for quantitative models to enable analytical capabilities of the DSS;
- knowledge base – provides the "brain" function for the DSS;
- user interface (UI) – the key element of DSS functionality (UI is the intermediate between the user and the system);
- user(-s) – important as any other DSS component (without the user, the functionality of the system's components is lost).

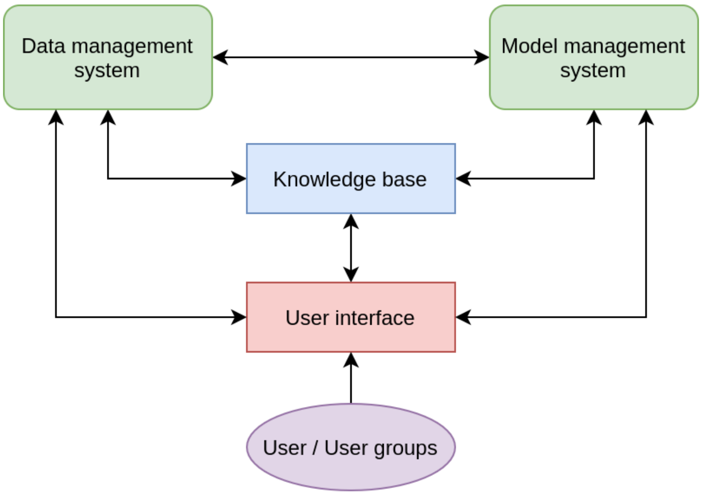

Figure 1. DSS architecture[7]

The list of components may vary, e.g., some authors distinguish three[8] or four[9] components where UI and users are merged together.

1.1 Decision making process

The decision-making process can be divided into several steps. One of the most popular models used for decision-making process involves a seven-step loop[10] (see Figure 2). Within this approach the emphasis is put on the development of models and problem analysis and some authors[11] suggest distinguishing four phases of the process:

- Intelligence phase;
- Design phase;
- Choice phase;

[7]Jaiswal, S. (2014). Decision support systems and business intelligence. [online] [accessed 11.12.2020]. Available at: https://www.slideshare.net/shwetabhjaiswal/decision-support-systems-and-business-intelligence
[8] Druzdzel, M. J., Flynn, R. R. (2002). Decision Support Systems, 1–15.
[9] Aronson, J., Liang, T., Turban, E. (2005). Decision support systems and intelligent systems. Yoyakarta: Andi, 24.
[10] Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., Carlsson, C. (2002). Past, present, and future of decision support technology. Decision Support Systems, 33(2), 111–126.
[11] Felsberger, A., Oberegger, B., Reiner, G. (2016). A Review of Decision Support Systems for Manufacturing Systems. In SAMI@ iKNOW

- Implementation phase.

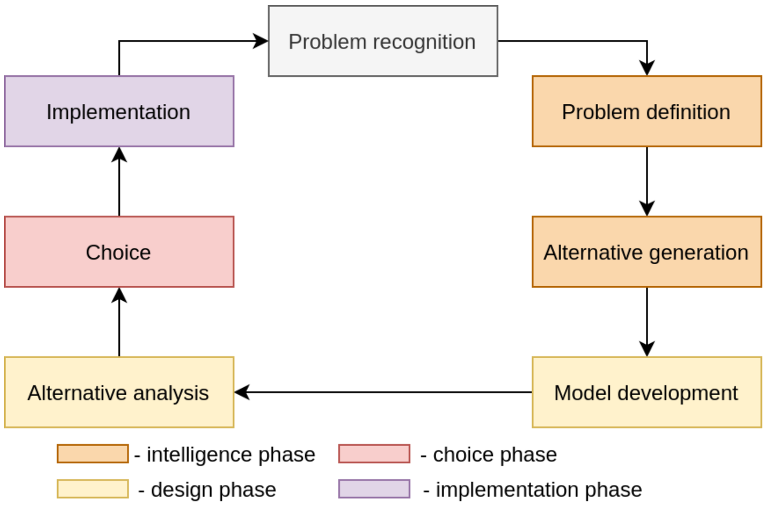

Figure 2. The decision-making process of a DSS[10,11]

However, those phases cannot be strictly divided, as they might overlap or even merge together, specifically, when dealing with a poorly structured problem.

In another modified decision-making process concept[12] it was suggested to distinguish a three--level structure, emphasizing to also use models in order to identify the state of a research object and to use not only one model, but several qualitative/ quantitative identification models (see Figure 3).

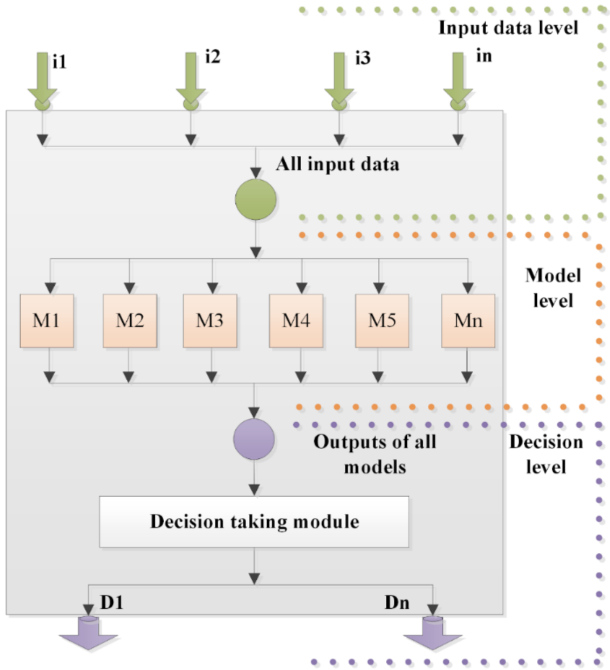

Figure 3. A three-level decision making process[12]

[12] Zacepins, A., Stalidzans, E. (2013) Information processing for remote recognition of the state of bee colonies and apiaries in precision beekeeping (apiculture). Biosystems and Information technology, Vol. 2(1), p. 6–10.

1.2 DSS in beekeeping

As described in the executive summary, the beekeeper is usually forced to visually inspect and to assess the status of a honeybee colony. This procedure is time consuming and may stress the colony. The active monitoring and remote sensing of appropriate information and communications technology (ICT) solutions may be a useful tool to support the management of honeybee colonies. Precision beekeeping (PB) is a scientific direction that combines ICT and beekeeping. Precision beekeeping is a sub-branch of precision agriculture and is defined as an apiary management strategy that focuses on individual bee colony monitoring and aims to minimize the resource consumption and maximize the productivity of bees[13]. Similar to that, PB also consists of a three-phase cycle (see Figure 4) – data collection, data analysis and application[13,14].

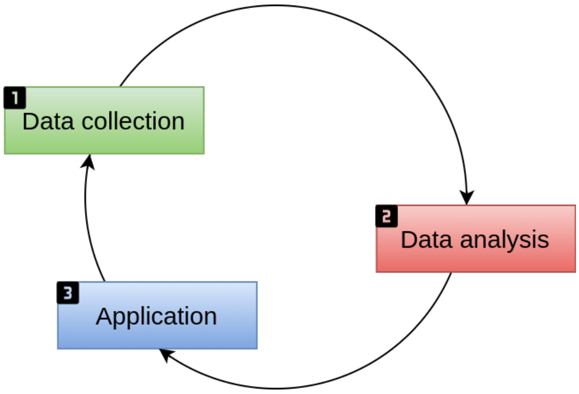

Figure 4. Three-phase cycle in precision agriculture[13]

In PB this cycle is described as:

(1) different colony parameters are measured and stored, to be

(2) analysed and interpreted in order to identify/ predict the bee colony status using specifically developed models together with a set of compiled information sources and expert knowledge to

(3) provide specific recommendations and describe possible reactions/ decisions and managemental actions which must be taken to ensure the health of the bee colony and improve apiary management.

Considering PB overall, the data collection phase of the three-cycle process is very well developed, but data analysis still requires improvement (development of robust methods/ algorithms to assist in data processing and analysing). The DSS is considered as a sub-system[14] of PB and is a tool for data analysis and interpretation to automatically provide important information about the status of bee colonies.

[13] Zacepins, A., Stalidzans, E., Meitalovs, J. (2012). Application of information technologies in precision apiculture. In Proceedings of the 13th International Conference on Precision Agriculture (ICPA 2012). Indianapolis, USA.
[14] Zacepins, A., Brusbardis, V., Meitalovs, J., Stalidzans, E. (2015). Challenges in the development of Precision Beekeeping. Biosystems Engineering, 130, 60–71.

Overall, one of the main characteristics of a DSS is that besides retrieving and displaying data, it also contains and applies different mathematical and statistical methods, generates reports, diagrams, tables etc. The simplest DSS examples include spreadsheets, statistical analysis systems and market forecasting software. How widespread the concept and use of a DSS is can be seen when looking at different fields such as the medical sector, agriculture, drought management, dam and reservoir operation.

Regarding the beekeeping sector, some DSS and ES examples can be found, but they are mostly devoted to apiary level management, focusing on multiple colonies as a group rather than an individual one with real-time measurements.

BEE AWARE[5] is an ES developed for honey bee diseases, pests, parasites and predator diagnosis and management. A similar solution, for pest diagnosis and recommendations on how to deal with them, has been developed in Greece[15]. There is also a DSS prototype[16] that assists the beekeepers in managing their colony placement near melliferous crops and tree species. Several studies[17,18,19,20] have been devoted to recognizing specific information about bee behaviour, detecting specific colony states.

Within the beekeeping field DSS rules (decisions) can be divided for PB data analysis, mainly in two groups/ categories – differential and individual[14] (see Figure 5). While individual rules focus on one individual colony the differential rules consider several bee colonies within one apiary or compare multiple apiaries.

Furthermore, these rules can be broken down as follows:

- Individual rules - death of the bee colony, intensive brood rearing period, broodless state, pre-swarming state, swarming state, queenless state, absconding state;
- Differential rules (within one apiary) - abnormal activity recognition (excitement/ stress, illness, lack of food, abnormal foraging activity);
- Differential rules (between multiple apiaries) - recognition of abnormal apiary.

[15] Mahaman, B. D., Harizanis, P., Filis, I., Antonopoulou, E., Yialouris, C. P., Sideridis, A. B. (2002). A diagnostic expert system for honeybee pests. Computers and Electronics in Agriculture, 36(1), 17–31.
[16] Vlad, V., Ion, N., Cojocaru, G., Ion, V., Lorent, A. (2012). Model and support system prototype for scheduling the beehive emplacement to agricultural and forest melliferous resources. Scientific Papers. Series A. Agronomy, LV, 410–415.
[17] Kridi, D. S., Carvalho, C. G. N. de, Gomes, D. G. (2014). A predictive algorithm for mitigate swarming bees through proactive monitoring via wireless sensor networks. In Proceedings of the 11th ACM symposium on Performance evaluation of wireless ad hoc, sensor, & ubiquitous networks (pp. 41–47).
[18] Kridi, D. S., de Carvalho, C. G. N., Gomes, D. G. (2016). Application of wireless sensor networks for beehive monitoring and in-hive thermal patterns detection. Computers and Electronics in Agriculture, 127, 221–235.
[19] Markovic, D., Pešović, U., Djurasevic, S., Sinisa, R. (2016). Decision support system for temperature monitoring in beehives. Acta Agriculturae Serbica, 21(42), 135–144.
[20] Edwards-Murphy, F., Magno, M., Whelan, P. M., O'Halloran, J., Popovici, E. M. (2016). b+ WSN: Smart beehive with preliminary decision tree analysis for agriculture and honey bee health monitoring. Computers and Electronics in Agriculture, 124, 211–219.

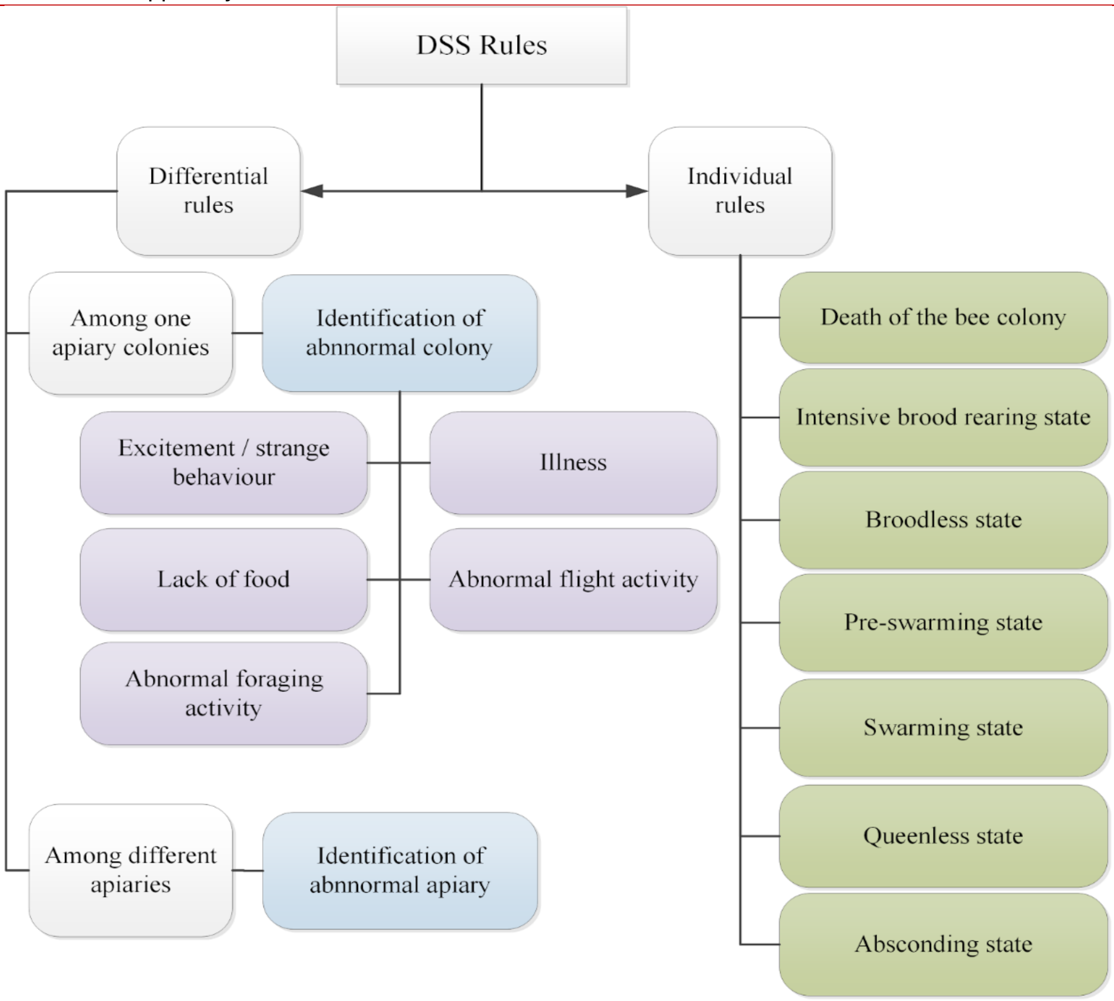

Figure 5. DSS rules for precision beekeeping data analysis[14]

2. Concept of the SAMS DSS

Within the SAMS project, the concept of a DSS was developed considering previously described DSS components and their functionality and taking into account the necessary steps required for the decision-making process (depicted in Figure 2, Figure 3).

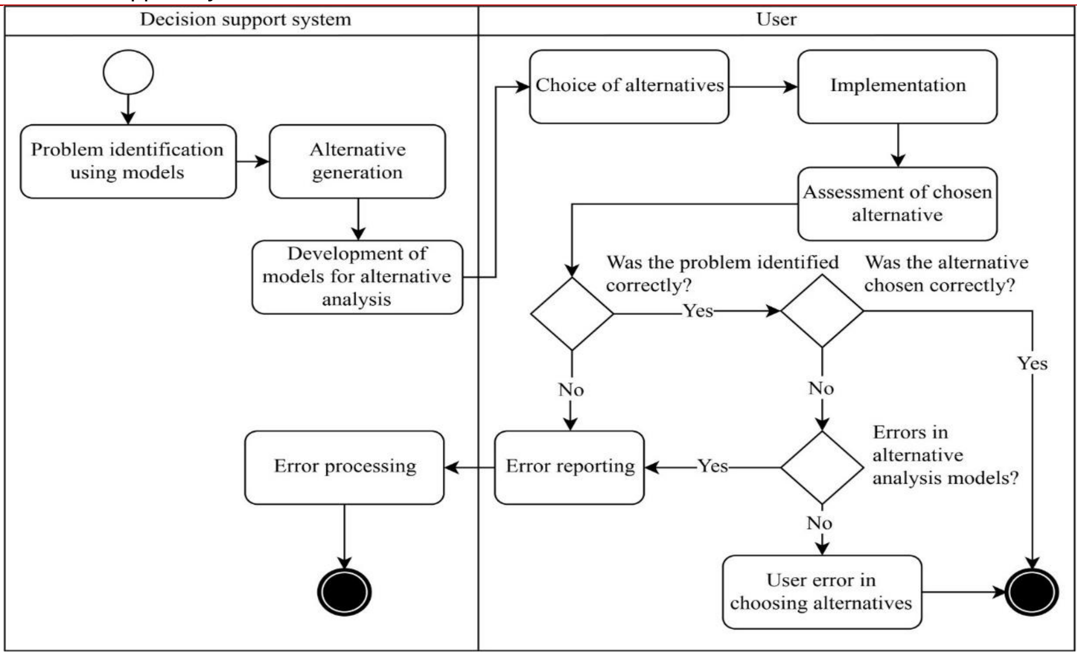

Figure 6. The DSS decision making concept[21]

The SAMS DSS decision making concept as well as the connected user actions is depicted in Figure 6, where an additional step is introduced – the assessment of the chosen alternative. This addition was based on the fact that such a phase is not emphasized enough in the literature, but it is very important in the beekeeping context, since it provides feedback about the whole DSS – from problem identification to alternative analysis and implementation (performed action)[21]. The SAMS DSS decision-making process in the beekeeping domain directly interferes/ overlaps/ connects with the user process and can be expressed in detail as follows:

- **Problem recognition/ identification** – this step seeks to answer questions like "Who will be the decision maker? Who will be the stakeholder?" In this case they are beekeepers. According to the beekeepers' needs (described in D2.2 User Centered Design – Results & Lessons Learnt and D6.3 Transfer Study on Data Utilization) as it is important for them to keep all of their colonies safe and to achieve maximum production since different bee behaviours can affect beekeepers' financial situation (less productivity). This means it is important to detect the colony state, e.g., rearing brood, foraging, swarming or absconding. Therefore, models need to be developed to timely recognize the critical bee colony states.
- **Alternative generation** – after the specific bee colony state is analysed next actions should be determined, e.g., when to travel to the apiary, when to do nothing. It should be mentioned that action "do nothing" is one of the important ones[22] – as every bee colony's on-site inspection more or less interferes with the work of bees (disturbs their flight activity/ foraging). Beekeepers should follow this advice: if you

[21] Kviesis, A., Komasilovs, V., Komasilova, O., & Zacepins, A. (2020). Application of fuzzy logic for honey bee colony state detection based on temperature data. Biosystems Engineering, 193, 90-100.
[22] Mizis, A. (2003). Darbi bišu dravā. Rīga: Avots.

don't know what to do at the apiary, do nothing. Basically, this suggests that beekeepers should not inspect colonies in order to simply satisfy their curiosity.

- **Development of models** – in this phase models for alternative analysis are developed. Swarming events can be mentioned as one example of alternative analysis. When this event occurs, it is not always financially viable to travel to the apiary to catch the swarm. In some cases, beekeepers may benefit more if they don't catch it and "let the swarm go". It highly depends on the travel time, the distance to the apiary, the number of beekeepers involved and the possibility that the swarm will be near the apiary.
- **Choice of alternatives** – based on the described analysis process the decision maker selects the most suitable/ appropriate decision.
- **Assessment of the chosen alternative** – this phase evaluates the made decision, meaning - if the problem has been identified correctly, if the analysis of alternatives provided the desired outcome. In this phase, the beekeeper himself/ herself must also assess if the choice (decision) was correct for the specific situation.

The proposed DSS concept characterizes the system as data, model and knowledge driven. The data and model management of the SAMS DSS is maintained within the SAMS DW Core (described in [D4.1 Report on data management]).

The complete SAMS bee colony (apiary) management concept is illustrated below (see Figure 7).

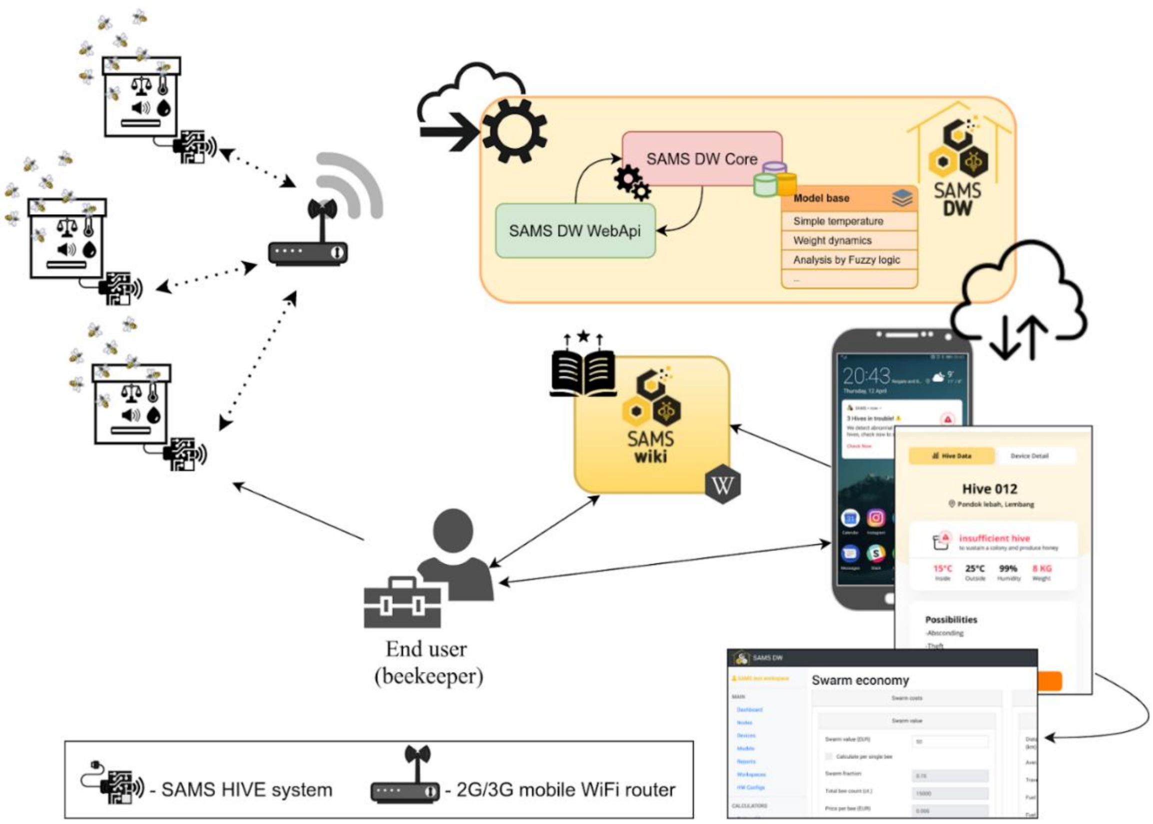

Figure 7. Apiary management concept with the usage of the SAMS DW, the integrated DSS and SAMSwiki

The concept depicted in Figure 7 includes all three phases of the precision beekeeping cycle and the earlier mentioned decision-making process concept[12]:

- **Data collection stage**: Collected data is sent to the SAMS DW and stored for further processing. Data collection is performed by using the SAMS bee colony monitoring systems (SAMS HIVE), which monitors the bee colony behaviour by collecting temperature, weight and sound data.
- **Data analysis stage**: the SAMS DW collects and analyses the data by using different models and approaches. The SAMS DW stores different models: a basic temperature model, weight dynamics as well as basic swarming detection model which is based on weight changes. SAMS DW also incorporates bee colony state detection based on temperature data that is analysed by the means of the application of Fuzzy logic and artificial neural networks (swarming detection) (described in D4.2 Report on Data Analysis and Interpretation). As a result of these models, bee colony states are identified.
- **Result interpretation and application**: Based on the identified colony states by the DSS, different management actions can be applied by the beekeeper. The beekeeper is informed about the possible actions/ recommendations through the UI, where the descriptions of the recommended actions are available on the SAMSwiki platform serving partly as an advisory support system (a system that provides advice and supports problem solving, is also considered as a type of ES[23]). The DSS point to the SAMSwiki, which includes various articles related to the beekeeping sector, bee biology, bee states etc. It acts as a knowledge base for beekeepers; therefore it does not only provide the recommended actions, but also educates the reader on beekeeping specifics. As an example the DSS detects/ recognizes the colony states and points to the SAMSwiki, where the specific case is described in more detailed, e.g., a broodless state is detected, the reader then is "forwarded" to the related SAMSwiki page, where the broodless state is described and recommendations are given. Then the beekeeper needs to decide what to do next by analyzing the alternatives. After the recommendations have been provided, the beekeeper can choose the appropriate alternative to perform some action or do nothing. This can be done by using an evaluation tool, like the swarm economics calculator which is developed in the DW.

To ensure the connection between the data analysis and its result interpretation (SAMS DW) and the application stage (SAMSwiki), the two platforms – SAMS DW and SAMSwiki – were linked together. A link to the SAMSwiki is provided within the data warehouse user menu under the section “knowledge base” (see Figure 8).

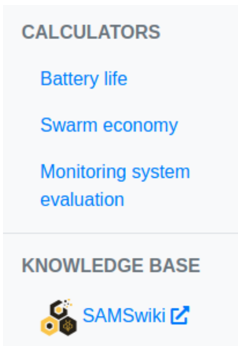

Figure 8. Link to the SAMSwiki in the SAMS data warehouse

[23] Beemer B., Gregg D. (2008) Advisory Systems to Support Decision Making. In: Handbook on Decision Support Systems 1. International Handbooks Information System. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-48713-5_24

A link to the related bee colony state description is provided next to the model output and is identified by the “i” letter in a blue circle icon (see Figure 9):

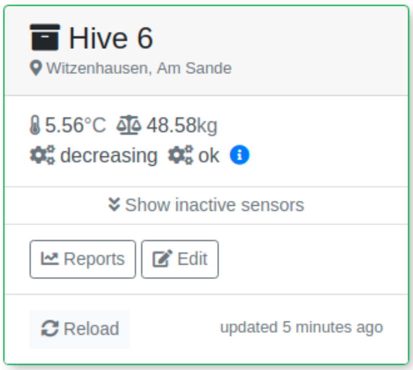

Figure 9. Link to the colony state description in the SAMSwiki

For example, if the DSS evaluates the colony status as death, then a link to this [state description and recommendations].

Within the SAMS project a prototype design of the mobile version of the SAMS DSS was developed (see chapter 4). In the mobile app recommendations can be proposed by the system users and evaluated by others as well (see Figure 10).

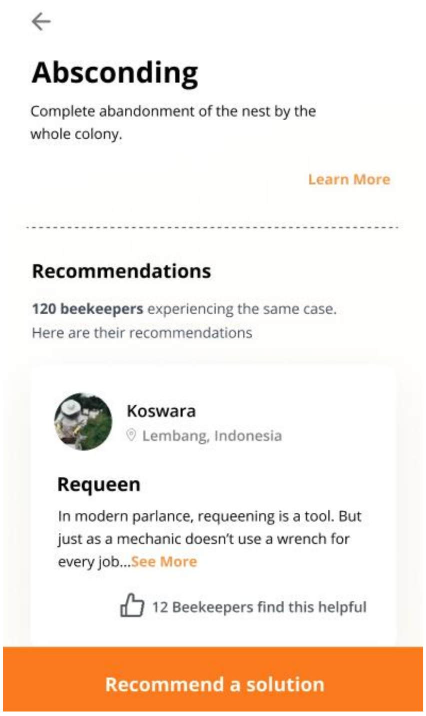

Figure 10. Design of the recommendation interface in the mobile application

2.1 Decisions about the bee colony states in SAMS

There are many bee colony states that can be identified and detected using various monitoring systems and their combinations. Beekeepers themselves need to decide what they want to detect; so which bee colony states are important to them. The table below demonstrates a summary of bee colony states and its importance for the beekeepers in Ethiopia and Indonesia.

Table 1. Ranking of the smart management possibilities for bee colony state detection in Ethiopia and Indonesia.

Event or State of the colony/hive	Importance to the beekeeper (less* to most important***)	Traditional detection methods	Parameter to measure	Technical Feasibility (easy* to complicated***)	Innovation (existing* to new***)	Predictability (- not; easy* to complicated***)
Absconding	***	Detection after event happened	Temp., weight	*	***	-
Death	***	Internal and external inspection of the hive	Temp., sound, weight	*	*	-
Start of the mass nectar flow	***	Observation of the flight activity outside the hive; internal inspection of the hive	Weight	*	*	Flowering calendar
Broodless	**(*)	External and internal inspection of the hive	Temp., sound	**	**	-
Queenless	**(*)	Internal inspection of the hive	Temp., sound	***	**	-
Colony Collapse	**	Detection after event happened	Temp., weight	*	***	-
End of the nectar flow	**	Internal inspection of the hive; observation of the surrounding environment (flowers in bloom)	Weight	**	*	**
Pre-Swarming	**	Internal and external inspection of the hive	Sound	***	***	-
Swarming	**	Detection of the swarmed	Temp., sound, weight	***	**	***

		colony (after event happened)				
Colonisation of an empty hive	?	External and internal inspection of the hive	Temp., sound, weight	*	***	-

***Bold events/ states** were identified to be the most relevant for the SAMS project. Asterisks (*****) rank the importance, technical feasibility, grade of innovation and predictability of each event or colony state.*

In relation to detect specific bee colony states the following table summarises which needed measurement and intervals (recommended and minimally required), are required, based on weight and/ or temperature measurements, to detect bee colony states.

Table 2. Summary of possible bee colony states with measurement intervals

Event or state of the colony	Parameter	Recommended interval	Required interval
Start of the mass nectar flow	Weight	Each 4 hours	1 per day
End of nectar flow	Weight	Each 4 hours	1 per day
Swarming	Temperature	Each 1 min	Each 5 min
	Weight	Each 30 min	Each 1 hour
Broodless	Temperature*	Each 30 min	Each 1 hour
Absconding	Temperature*	Each 1 hour	1 per day
	Weight	Each 1 hour	Each 4 hours
CCD	Temperature*	Each 1 hour	1 per day
	Weight	Each 1 hour	Each 4 hours
Death	Temperature*	Each 1 hour	1 per day

As it can be seen from the table above, many colony states can be identified by continuous weight measurements, since the dynamics of the hive weight can tell much about the colony behaviour and actual state. It should be mentioned that the measurements must be taken real-time in order to get a timely response from the DSS. Regarding SAMS, the country-specific infrastructure and other technical aspects had a major impact on real-time continuous monitoring, therefore SAMS mostly worked with/ provides historical data, since the infrastructure aspects are out of SAMS scope.

2.1.1 Decisions based on weight dynamics

Within the data warehouse several decisions are made based on the weight dynamic:

- **Consumption of food resources.** During the passive period, when foraging resources are not available, bee colonies must use previously collected resources for living. Food consumption depends on many factors, including the size of the colony and environmental conditions as they consume less food when they are in a cluster.

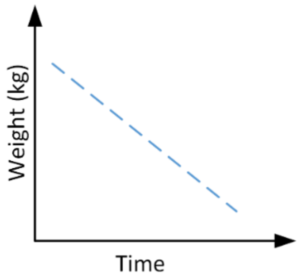

Figure 11. Visualisation of food resource consumption

Example of real data:

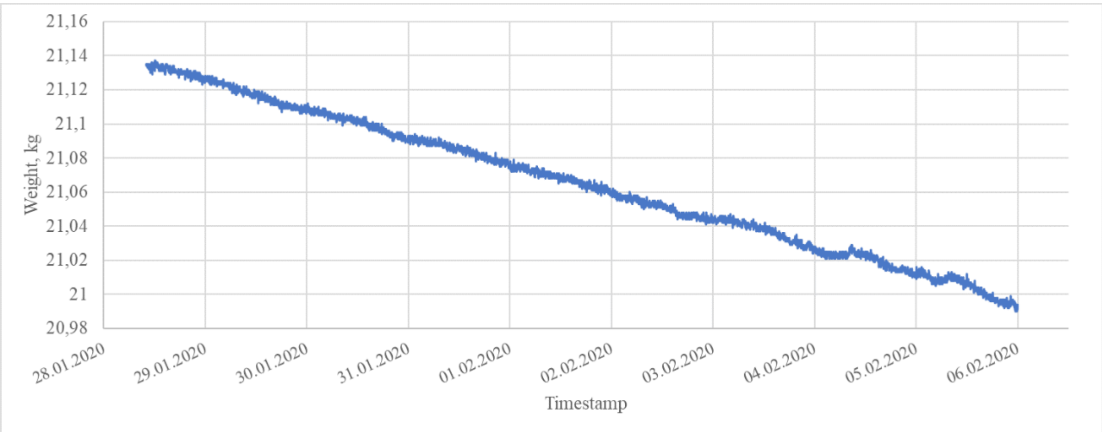

Figure 12. Real weight data demonstrating bee colony food consumption during the passive wintering period in Jelgava, Latvia, during January and February 2020. The colony was placed in a controlled environment - specific wintering building[24] in order to improve the honeybee wintering process (specifically for weaker colonies)

- **Continuous nectar flow.** During the active foraging period, when resources are widely available a bee colony can forage very intensively thus increasing the hive weight. Such a situation can last for several days, depending on environmental conditions and resources available.
- **Swarming event**. Sometimes the bee colony can swarm. Bee colony swarming is a natural way of proliferation of the bee colony. It occurs when more than one queen lives within the colony. The old queen leaves the colony with a group of worker bees

[24] Zacepins, A., Stalidzans, E. (2012). Architecture of automatized control system for honey bee indoor wintering process monitoring and control. In Proceedings of the 13th International Carpathian Control Conference (ICCC) (pp. 772-775). IEEE.

to establish a new colony in a different place at least some kilometres away from the current abode. During the swarming event a part of the bees leave the initial colony to build up a new one. During the swarming half of the bees leave the hive which results in a decrease in weight of about 2kg or more (if the colony is large, consisting of 50 000 bees) as one bee weights about 90mg.

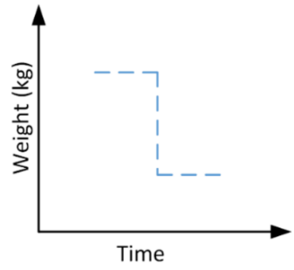

Figure 13. Visualisation of the model for bee colony swarming

Example of real data:

Figure 14. Real temperature and weight data demonstrating bee colony swarming in Witzenhausen, Germany, in early June 2020. The orange line represents temperature within the hive, blue – weight of the colony

2.1.2 Decisions based on temperature monitoring

After the weight measurements, temperature monitoring of a single colony can lead to an understanding and identification of several states (in more detail temperature data analysis is described in D4.2 Report on Data Analysis and Interpretation). Below are some examples that show a glimpse of how the temperature dynamics look like.

- **Brood rearing state.** During this state the bee colony should maintain stable temperature to provide the needed amount of heat for the new brood. Temperature in the colony is stable at any environmental temperature and is about 35℃.

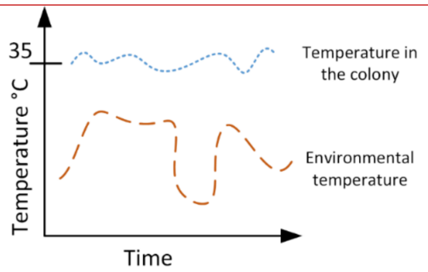

Figure 15. Visualisation of the model for bee colony brood rearing state

Example of *real data:*

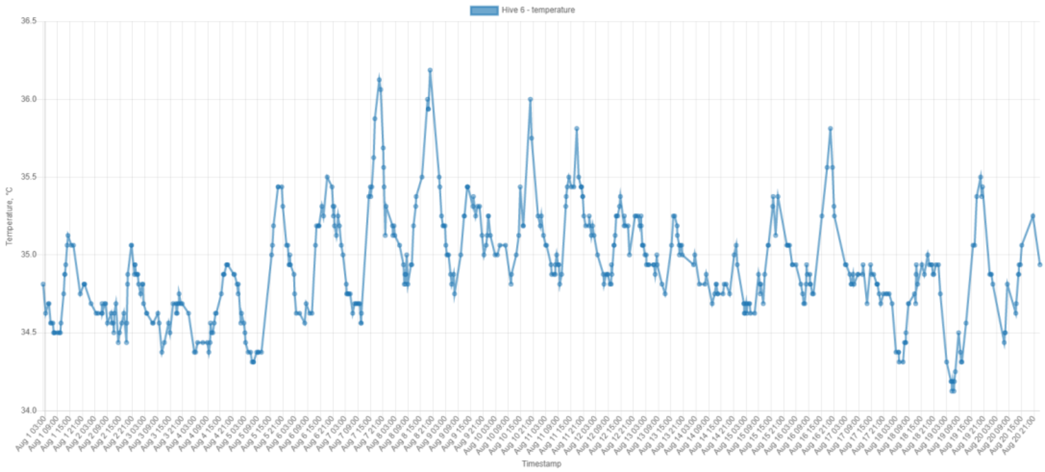

Figure 16. Real data demonstrating bee colony brood rearing in Witzenhausen, Germany, in August 2020. The temperature is kept stable between 34°C and 36°C

- **Death of a colony.** The integrity of a beehive and the death of a bee colony in the hive can be detected by looking at the temperature data. The death of a bee colony can be registered if the average temperature in the hive is equal or very close to the ambient temperature. Early detection and registration of the death of an individual colony can be valuable information for beekeepers, enabling them to react quickly and prevent further losses if necessary. The simultaneous death of several colonies may be a result of extreme weather conditions, demolition or CCD.

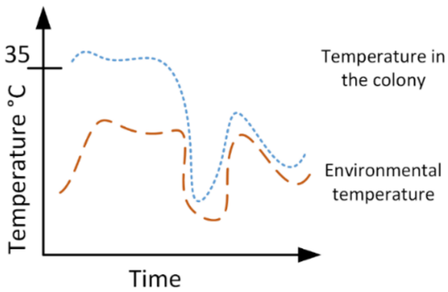

Figure 17. Visualisation of the model for bee colony death

Example of *real data:*

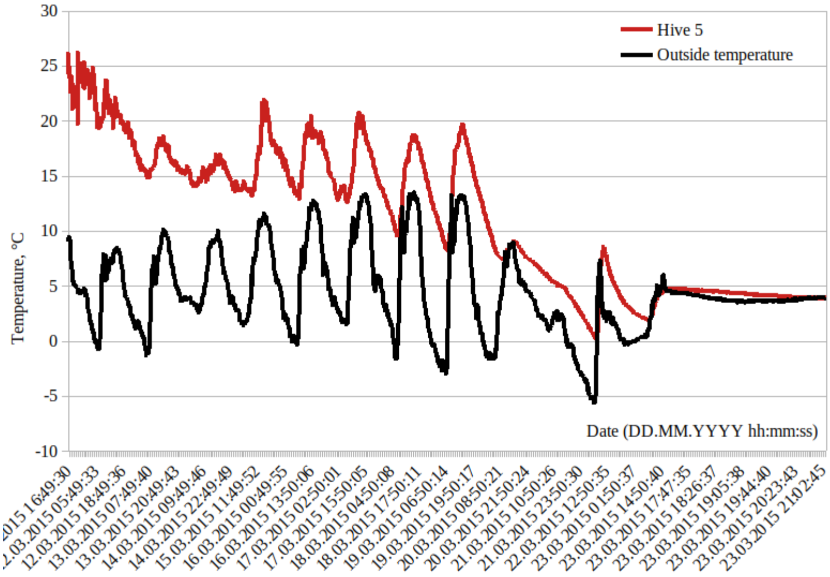

Figure 18. Historical data of the ITAPIC ("Application of Information Technologies in Precision Apiculture") (EU funded within ICT-AGRI 2012 FP 7) project obtained from previous observations demonstrating bee colony death in Jelgava, Latvia, in March 2015. During the SAMS project no colony death was observed. The red line represents temperature within the hive, black - outside

- **Swarming.** . During the swarming event, the temperature increases (from ~1.5°C to even ~4°C) for a short period of time (around 20 min) and then it comes back to normal. This increase in temperature can be detected by the temperature sensor if measurements are taken often enough (every 1-5 min).

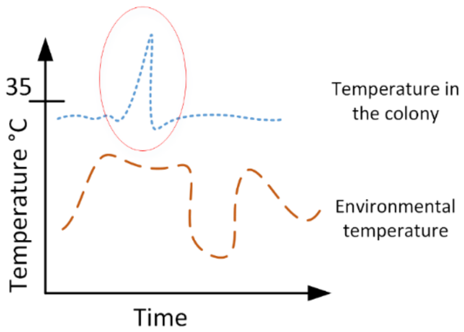

Figure 19. Visualisation of the temperature model for bee colony swarming

Example of real data:

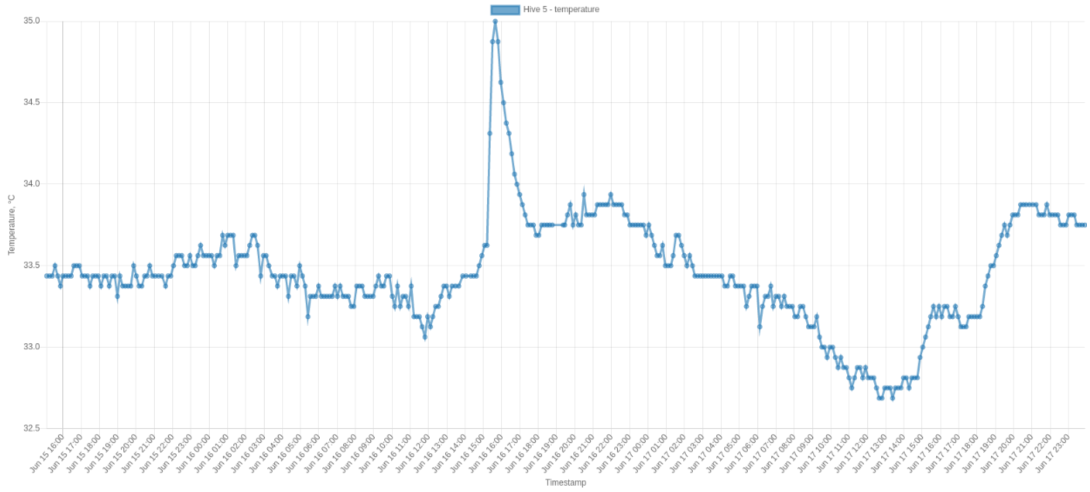

Figure 20. Real temperature data demonstrating bee colony swarming in Witzenhausen, Germany, in mid-June, 2020

- **Passive state.** During the wintering passive state bee colony should create a comb to efficiently maintain stable and minimally needed temperature for the wintering. The temperature is usually below 10℃

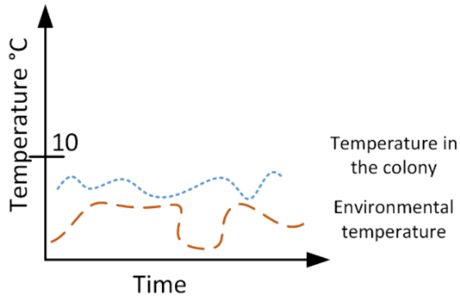

Figure 21. Visualisation of the temperature model for bee colony passive state

Example of real data:

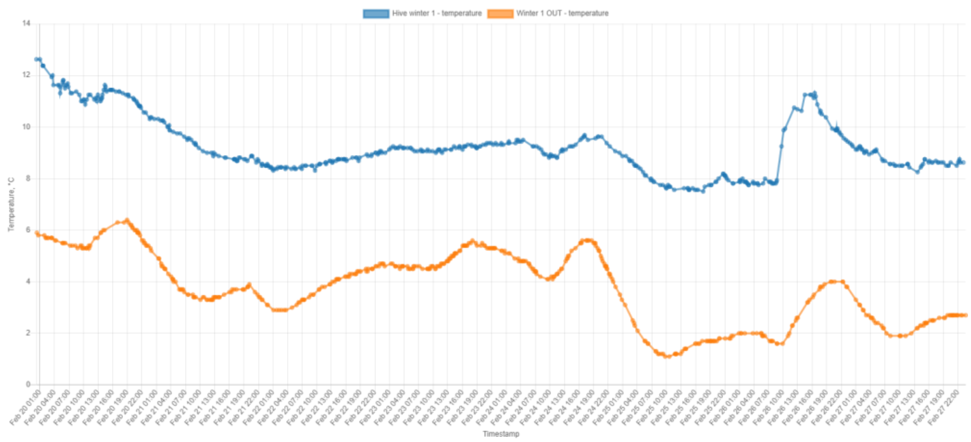

Figure 22. Real temperature data demonstrating bee colony passive state during February 2020, in a wintering building in Jelgava, Latvia. Blue line represents the temperature inside the hive, orange - outside

- **Broodless state**. Temperature measurements can be used to detect this state, as broods in the nest force the bees to maintain a stable high temperature (about 35℃) and compensate for the changes in ambient temperature whereas the temperature in broodless colonies is much more dependent on the ambient temperature.

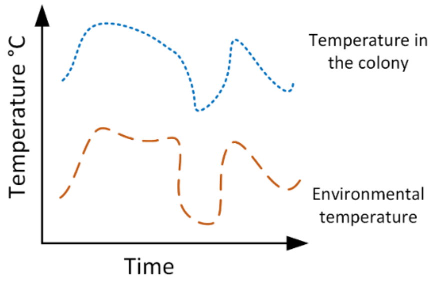

Figure 23. Visualisation of the temperature model for bee colony broodless state

Example of real data:

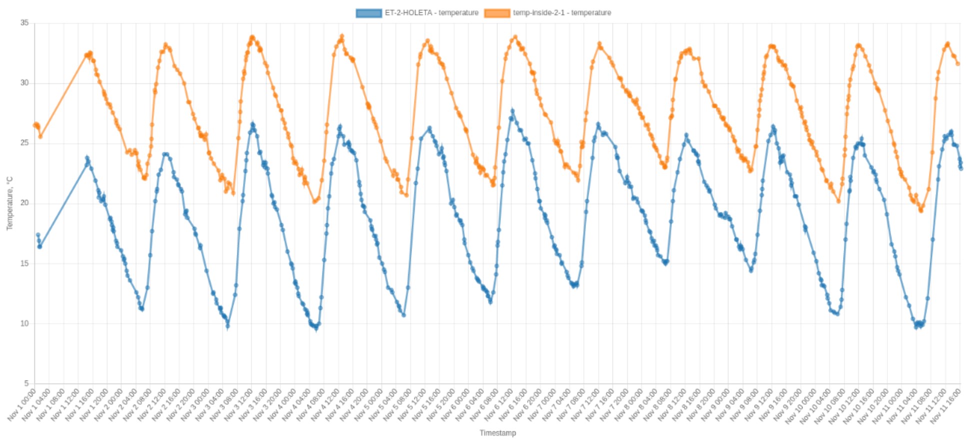

Figure 24. Real temperature data demonstrating bee colony broodless state in Ethiopia during November 2020. The orange line represents the temperature inside the hive, blue - outside

2.2 Alternative analysis

Using a DSS in the beekeeping field slightly differs from the way it is used in other fields or industries (usually to assist in different kind of planning purposes, e.g., company managers use it for various planning (supply chains) purposes; traffic operators use it to manage/ plan traffic during major events in a city; farmers use it for crop planning and field management to get higher yield). In precision beekeeping and therefore in the SAMS context, the DSS is mainly used for data interpretation in order to recognize different colony states.

As previously described, an important step in the decision-making process is the alternative analysis. So, what does the beekeeper need to do next, when a colony state is detected? The beekeeper needs to choose between alternative actions. In this case, the alternative analysis step of the DSS can mainly provide two alternatives – inspect and manage the bee colony or do nothing. Appropriate models should be used to choose the most appropriate alternative.

For the swarming event a calculator was developed within the SAMS DW (see Figure 25) that allows the beekeeper to assess whether it “pays off” for him/ her to travel to the apiary and catch the swarm or if letting the swarm go would cost him/ her less (so to choose between catching a swarm or doing nothing). The calculator integrates a mathematical model that includes various aspects, like travelling costs to the apiary, the number of people involved and the approximate value of the swarm.

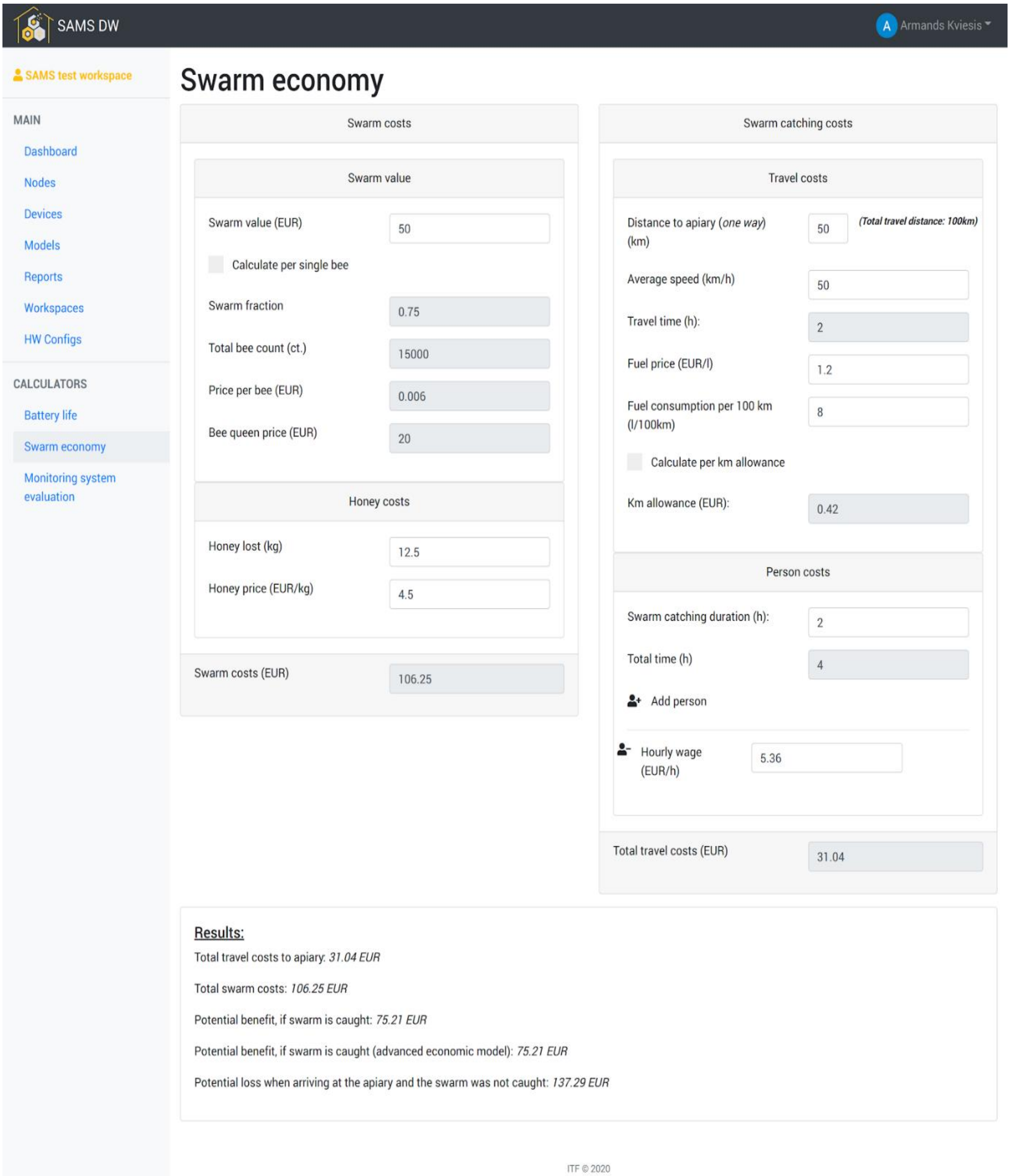

Figure 25. Calculation of alternative analysis within SAMS DW

The calculator consists of several blocks:

- **swarm costs**:
  - **swarm value –** several sources[25,26,27] state it is hard to determine the value of a swarm, but usually during a first swarming event it can be up to 75% of the worker bees that leave the hive. Such a large swarm, if not caught, can bring significant losses to the beekeeper. Usually there are two strategies that beekeepers use – (1) one is to let the bees back in the hive from which they swarmed; (2) another is to place them in a new hive by creating a new colony. Due to the behaviour the original colony is weakened, and it will not produce the same amount of honey as a non-swarming colony. Therefore, without catching the swarm, the beekeeper can lose honey, so therefore income, or also the possibility to have a new colony. To determine the swarm value, two methods can be applied – based on the assumption on literature, e.g., (1) typically the swarm is valued to be around 21-43 EUR[22] or (2) theoretically calculate the value by taking into account the price of one bee (~0.005 EUR)[28] and the price of a queen (~20 EUR);
  - **value of the honey** – within some reports[29] it can be found, that bees are considered to produce 2-3 times less honey due to swarming, sometimes the colony can´t even produce enough resources for themselves to overcome the cold winter periods. In a good season, a bee colony can produce 30kg and more of honey. It should also be mentioned that in such case of a swarming event, the swarming bees consume a large amount of the already collected honey that they could stay alive ("survive") until they settle in the new place. Although there are not many studies which focus on the economical aspect that might be affected by bee swarming, but the impact on the produced honey amount is significant, due to various factors as previously described. Therefore, such aspect needs to be taken into account
- **swarm catching costs**:
  - **travel costs** – parameters such as distance to the apiary (both ways), price of fuel, fuel consumption by car, time spent on the road. All this sums up the total travel costs;
  - **person costs** – describes the costs of the persons involved to catch the swarm on the beekeeping site. This calculation considers the person count, time spent and hourly wage.

[25] Rangel, J., Seeley, T. D. (2012). Colony fissioning in honey bees: size and significance of the swarm fraction. Insectes Sociaux, 59(4), 453–462.
[26] Caron, D.M., Dewey M. & Connor, L.J., 2013. Honey bee biology and beekeeping
[27] Winston, M.L., 1987. The Biology of the Honey Bee, Cambridge: Harvard University Press.
[28] So what does the average honey bee cost? (2011). [online] [accessed 10.12.2020]. Available at: https://www.honeybeesuite.com/so-what-does-the-average-honey-bee-cost/#:~:text=Your%20cost%20per%20bee%E2%80%94dead,10500%20bees%20or%200.52%20cents
[29] Rodionovs, V., Šabaršovs, I. (1983). Ja jums ir bites. (R. Kļaviņa, Ed.). 79 Rīga: Avots.

The calculator can be used not only to assess the benefits and losses in swarming cases, but parts of it also to assess different aspects in general.

3. Demonstration of the developed models

Basic bee colony state identification models were developed in order to demonstrate the data analysis, model implementation and the display of the output data to the end user. The models are based on temperature and weight data.

3.1 Models related to bee colony temperature monitoring

The name of the model is "Simple temperature delta model", which can be used to identify if the colony is still alive or not.

This model uses two parameters: (1) bee colony internal temperature compared to (2) environmental (outside) temperature. If the defined difference between those two temperatures is outside the threshold, it is assumed that the bee colony is dead (status is *not ok*), otherwise it is alive (status is *ok*).

By default, the system's user can see the model outcome in the dashboard next to the hive or its element section. Furthermore, it is possible to explore the detailed view of the model operation in the report section, where all model outcomes are presented. It is also possible to see the model parameter values.

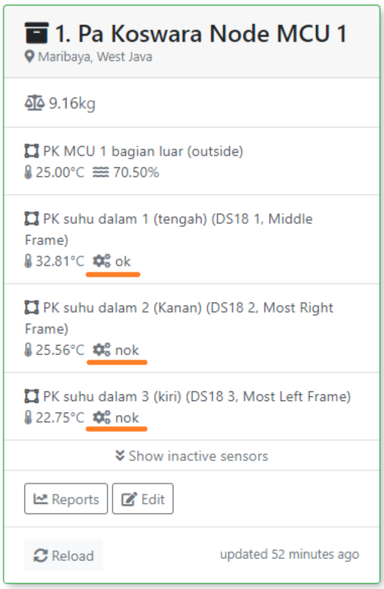

Figure 26. SAMS DW dashboard with an implemented simple model. The model was applied to a monitored hive (temperature in 3 positions of the hive) in West Java, Indonesia. The model outcome is shown by two values "ok" and "nok" (underlined)

Before the user can use models, they must be predefined by the platform administrators in the system's back-end (server side). Afterwards predefined models can be chosen and linked to the hives by the user by assigning needed model parameters.

To create a description of a model the user should go to the model section within the SAMS DW:

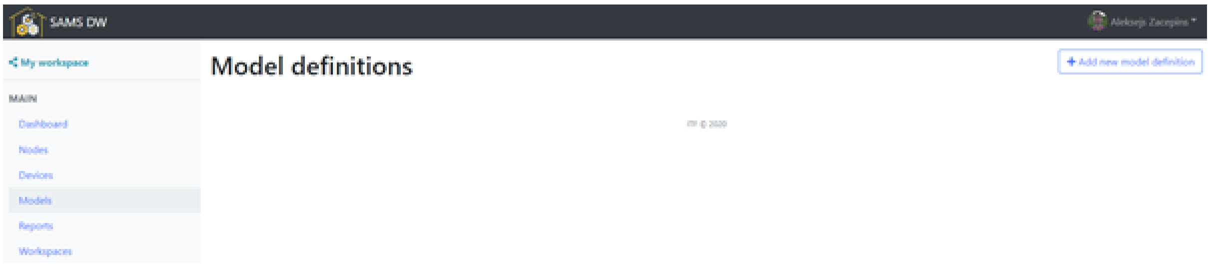

Figure 27. Definition of a model in the DW

Then button “+ *ADD new model definition*” should be clicked and the required model template should be chosen from the list:

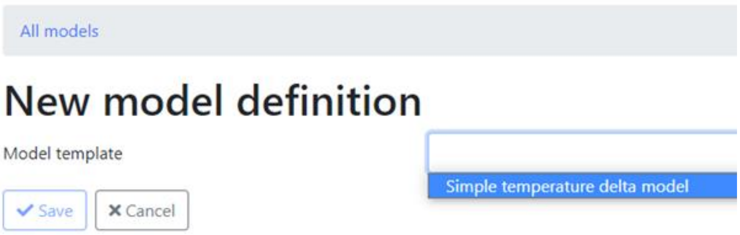

Figure 28. Choice of a model

After this step the required parameters should be assigned for a proper model operation:

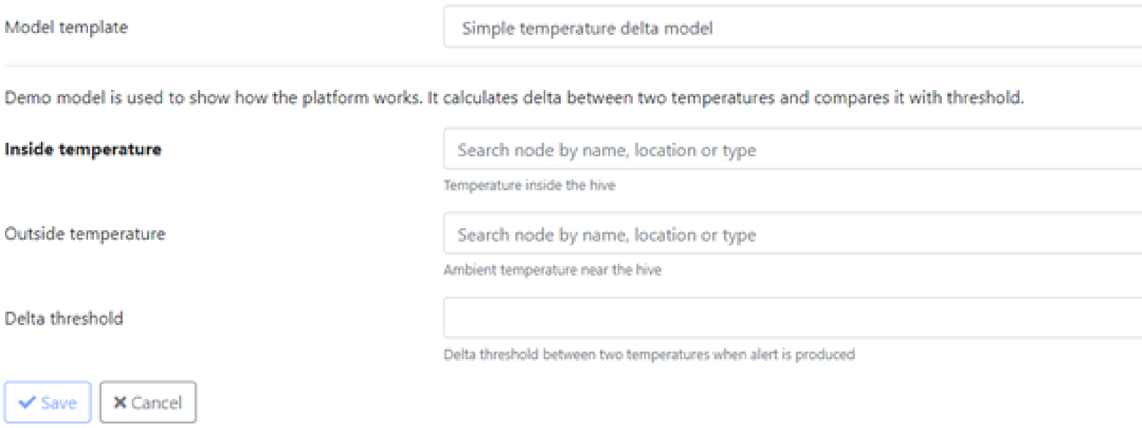

Figure 29. Definition of the model parameters

An example of such a model is shown in the chart below:

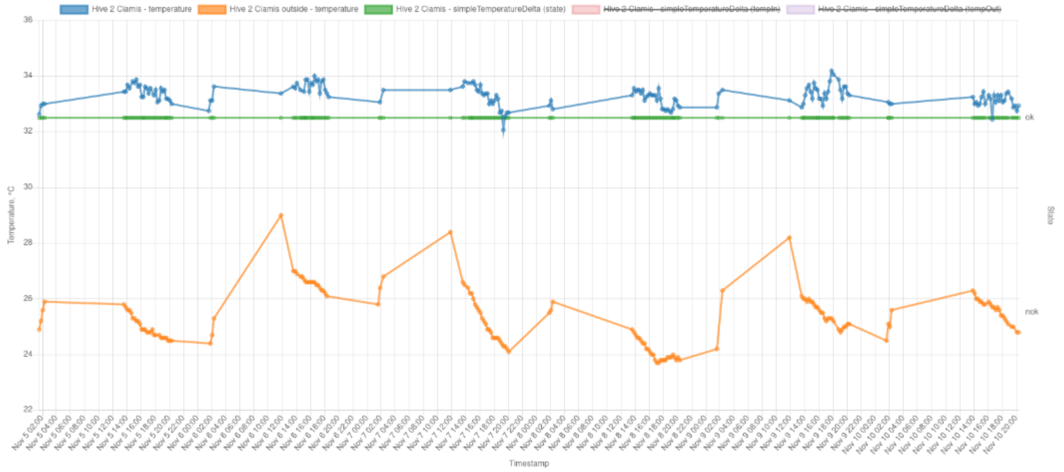

Figure 30. Demonstration of a simple temperature model. The green line shows if the colony status is "ok" or "nok" (vertical axis on the right side of the chart)

3.2 Models related to the bee colony weight monitoring

Several basic models are implemented in the DW to demonstrate the outcome of the weight monitoring.

- **Weight dynamic model:** this model provides a decision on whether the bee colony overall weight has a positive or negative dynamic. Some users/ beekeepers might be willing to follow the weigh dynamics of the bee colony by week, some - by day. Depending on such needs, they can choose the time interval that suits them best. Then the model draws a linear trend and provides the output to the user based on defined alfa range. This means that users need to define the slope coefficient for the model ($y = a + bx$). This is provided at model definition view and called *"Weight change dynamics"* (see Figure 31). The slope describes the rate of change between the independent and dependent variables; in other words, the rate of change describes the change that occurs in the dependent variable as the independent variable is changed.

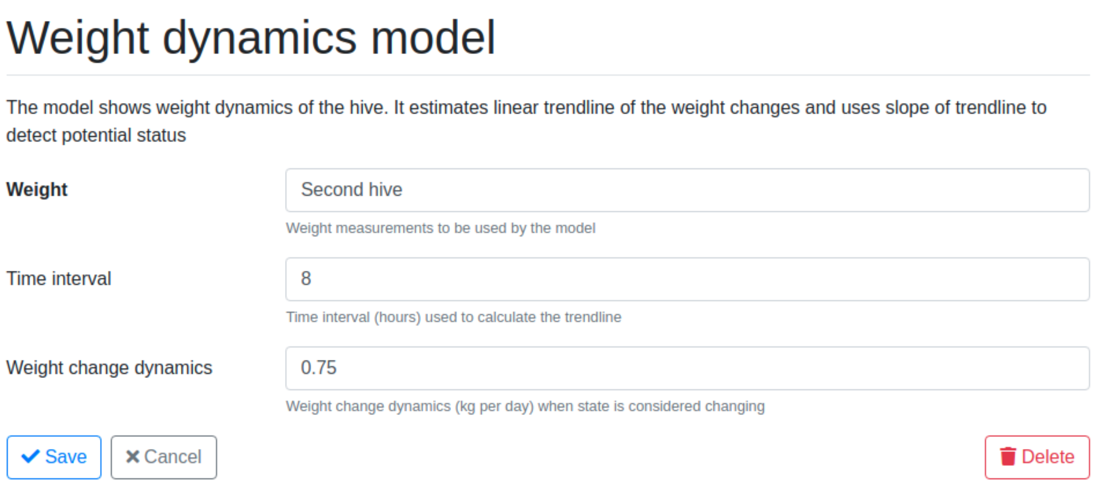

Figure 31. Configuration of a weight dynamic model

The outcome of the model is demonstrated in Figure 32. All three different states (orange line) are presented (decreasing, steady, increasing) while the blue line represents the weight dynamic of the bee colony. Random generated data was used to validate and present the model operation.

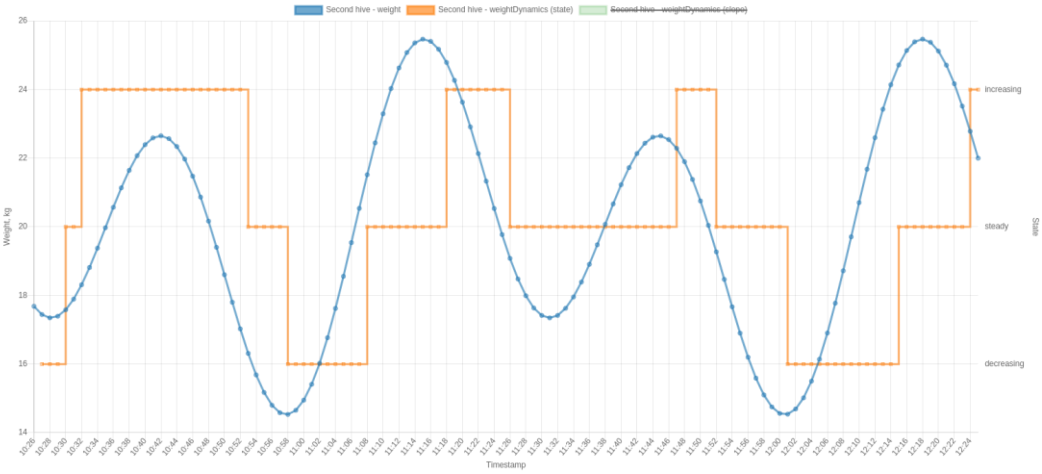

Figure 32. Demonstration of a weight dynamic model

- **Swarming detection model**: Another weight model provides a decision about the possible bee colony swarming event. An important input parameter is the weight delta which is used in this detection model.

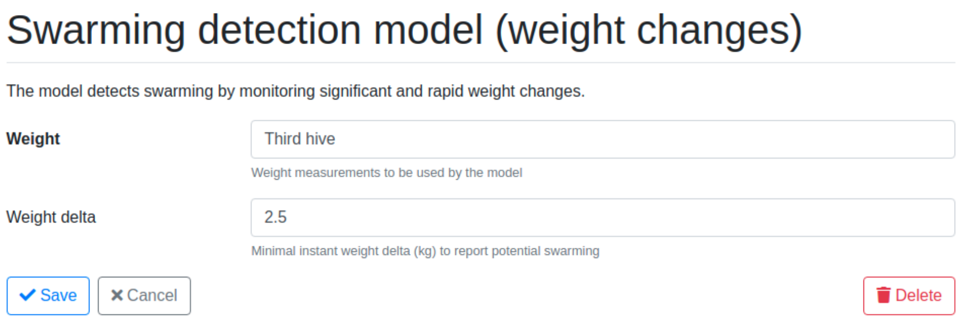

Figure 33. Configuration of a swarming detection model

The outcome of the model is demonstrated in Figure 34, where the orange line demonstrates the swarming state while the blue line represents the weight dynamic of the bee colony. Random generated data was used to validate and present the model operation.

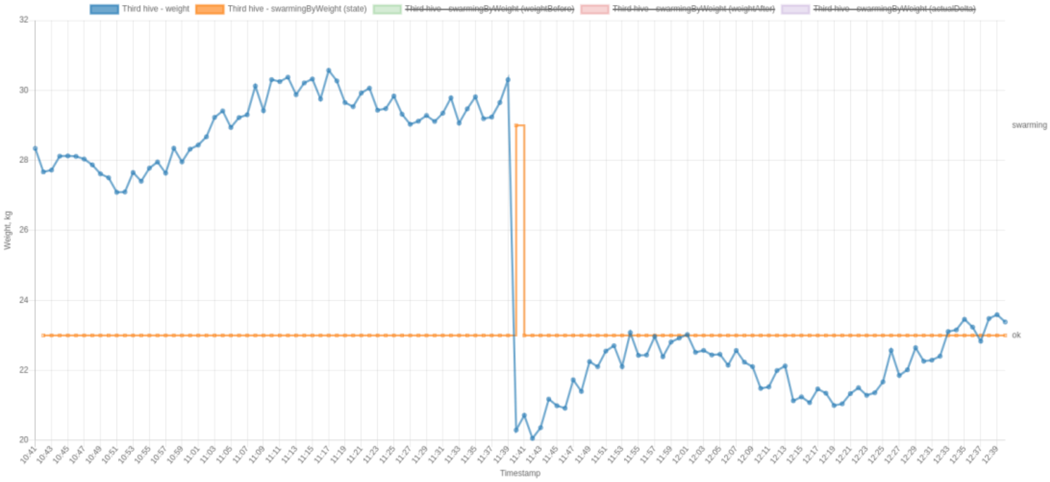

Figure 34. Demonstration of a swarming detection model

4. DSS user interface design

As it was mentioned describing the DSS architecture (ref. to chapter 1), user interface plays an important role in the whole system. Without a properly designed UI, user cannot use the system to its full potential. Therefore, during the User Centered Design research (UCD), a UI for DSS mobile application was designed by considering user needs and feedback during the development process. An example of the app, where a hive that needs beekeeper's attention, is shown in Figure 35.

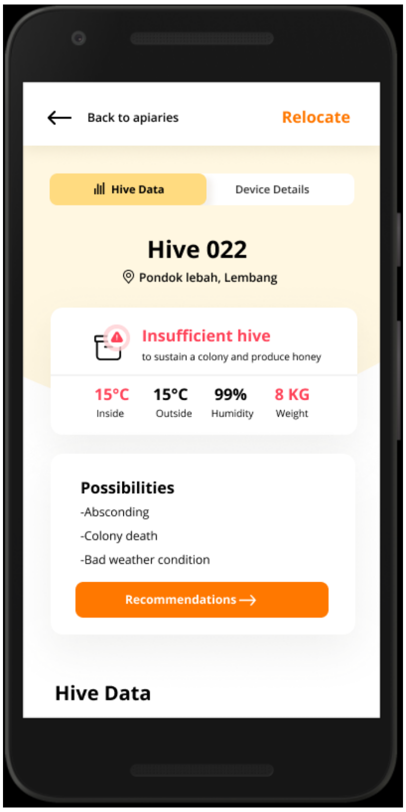

Figure 35. Example of the developed UI design for DSS

In more detail this mobile application design is described in D2.2 User Centered Design – Results & Lessons Learnt, D4.3 Evaluation of Responses and Support Services. The design is publicly available and can be developed/ elaborated further by any interested party.

5. Additional decision support services for the beekeepers

Within the SAMS project several online services were developed to assist beekeepers in choosing the right monitoring system configuration and in evaluating the monitoring system lifetime based on energy consumption.

5.1 Calculator to evaluate the economic benefits of the remote monitoring system

To ease the process of formula calculation and to evaluate the economic gains of the implementation of the bee colony remote monitoring system, an online web tool (application) was developed and published. The calculator is pre-filled with default values, and the user can adapt them to their local requirements (needs, peculiarities) and prices (costs). The web tool was integrated into the SAMS DW under "calculators" section. Results are calculated simultaneously as soon as the required fields are filled in. A screenshot of the developed tool is shown in Figure 36:

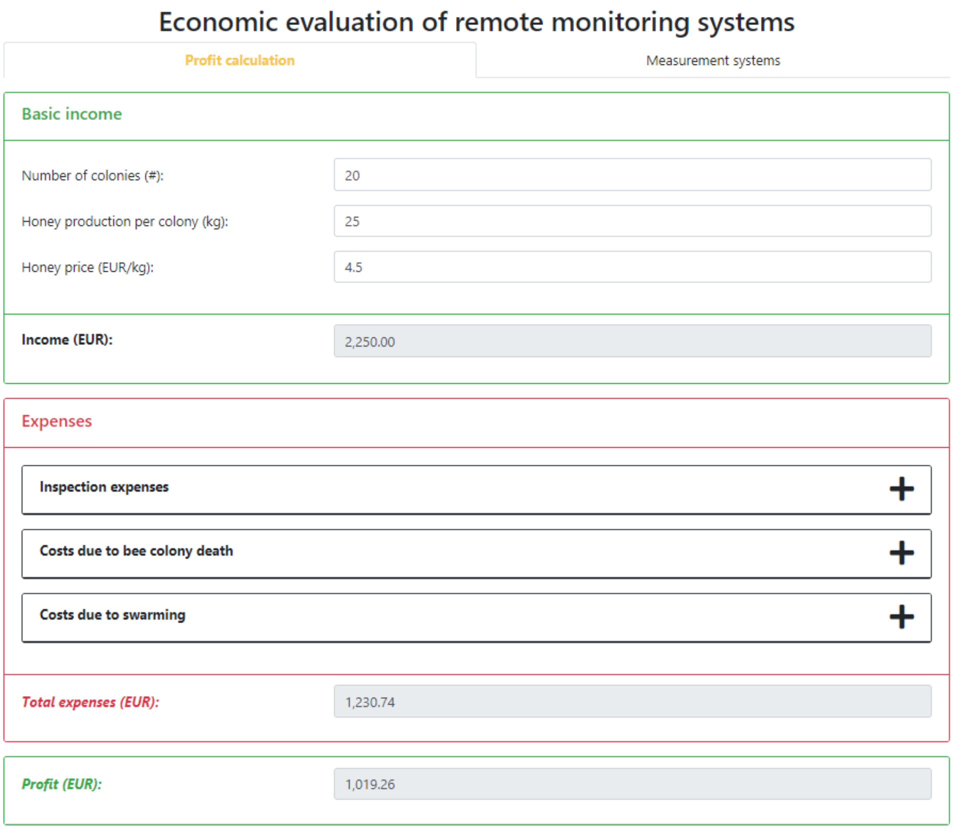

Figure 36. Calculator for economic evaluation of a remote monitoring system

The economic evaluation consists of two parts: (1) income and (2) expenses. The income position is simplified and considers the number of colonies, average honey production per colony and honey market price, while the expenses are divided into several categories: (1) costs associated with the manual inspections of the colonies, (2) costs due to the bee colony death and (3) costs due to the swarming. Knowing this basic income and expense position, economic evaluation of the remote monitoring system can be done. Several different scenarios are proposed and summarised in the web calculator (see Figure 37).

Economic evaluation of remote monitoring systems

Profit calculation | Measurement systems

	Without IT system	All hives with measuring system	One hive with system	Apiary with custom config
Production per hive	25.00	31.25	28.75	30.00
Basic income	2,250.00	2,812.50	2,587.50	2,700.00
		Expenses		
Number of inspections	12	7	12	7
$EXP_{inspections}$	458.24	267.31	458.24	267.31
Number of dead colonies	4	3	4	3
EXP_{dead}	560.00	458.19	560.00	458.19
Number of swarmings	2	0	2	0
$EXP_{swarming}$	212.50	0.00	212.50	0.00
EXP_{total}	1,230.74	725.49	1,230.74	725.49
		Profit and system installation costs		
Profit	1,019.26	2,087.01	1,356.76	1,974.51
System installation costs	---	5,780.00	289.00	500.00

Figure 37. Comparison view in the web calculator

The best option for beekeepers is to use custom configuration of the devices for the bee colony real-time remote monitoring to fully utilize the potential of the monitoring system and to make use of all the benefits. In this configuration there would only be one main automatic device to monitor weight changes of one controlled hive as it can be assumed that bee colonies which are located in the same area will more or less have a similar weight as the forage is the same. Nevertheless, all other hives would be constantly monitored and equipped with temperature and/ or sound/ vibration, sensors to detect, e.g., swarming. Based on that concept the beekeeper will gain all benefits – detect swarming, minimize risk for colony death and have possible increase in production.

5.2 Bee colony monitoring system's battery life calculator

Data can only be collected if the installed monitoring systems are powered. Therefore, the monitoring systems battery life calculator provides the ground for enabling the beekeeper to detect colony states in their hives. The battery life depends on the intervals of measurements, e.g., if the system measures all parameters every 30 seconds and runs on four 1900mAh batteries, then theoretically the system can operate for 5 days. The battery life calculator was developed and is integrated within the SAMS DW as a web application and is publicly available. The calculator allows the user to estimate what effect the measurement interval (this could be defined as the duration of a sleep mode) has on the whole battery life of the monitoring system.

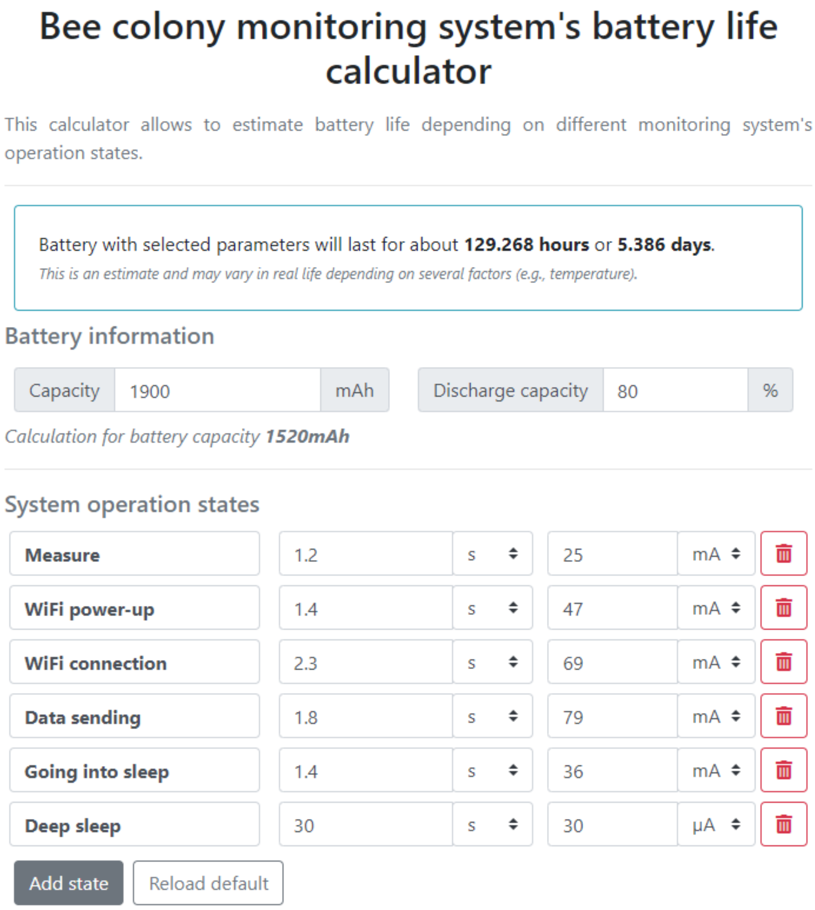

Figure 38. Calculator for bee colony monitoring system's battery life evaluation

Project website: www.sams-project.eu

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