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Into a New Home

Voting Methods for Honeybees Nest Site Decision-making

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Master's Thesis

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Contents

Acknowledgments

Abstract

Every day, we make social decisions, but this is not limited to humans; almost every living thing must make a decision at some point. When we look closer, we can see that creatures that live in groups have social choices. These social options are provided for the community's well-being and continuity. In our study, we explain the decisions that honey bees make when choosing a new hive location and how they make them. While honey bees use the majority voting technique when making social decisions, we investigated what would happen if they used different voting methods in our study, such as Borda Count and Liquid Democracy. In our simulations, we imitated honey bees' real-life efforts to find a new home; we analyzed and compared the consensus points they reached using Majority, Borda Count, and Liquid Democracy voting methods. In our research, we discovered that the majority voting method yields a higher rate of consensus than other voting methods with higher accuracy on the best potential hive.

1 Introduction

One of our community's unspoken laws is that we develop a theoretical framework for analyzing individual ideas, preferences, interests, or welfare in order to achieve a collective choice or, in some ways, social welfare. It's not always easy to come to this communal choice, but it's a circumstance we find ourselves in most of the time. Humans, animals and colony-dwelling insects utilize collective decisions to gauge the quality of prospective options. Humans normally live in highly developed societies, which means that many critical choices are decided by groups of individuals working collectively rather than by individuals acting alone. Human collective decisions span from small-scale decisions made by families, friends, or coworkers to large-scale decisions such as national democratic elections and international treaties. It is apparent that human communities cannot function without making collective decisions, and simple issues that cannot be handled in our time are due to people's incapacity to achieve an agreement. (e. g. The Kyoto Protocol[1])
We benefit from collective decision-making just as much as other animals and insects do. Homing and migratory birds plan their routes together, which raises their chances of survival and migration success[1]. Bats share roosting areas with one another, resolving a crucial aspect of their existence through solidarity and collectively [2]. Eusocial[2] insects and communal breeders, which provide fodder to the hive, raise young and seek prey [3], shoals of fish [4]. Moreover, honey bees, the topic of this study, have been seen to make social judgments while seeking a new colony, when faced with danger, and in other scenarios [5]. Collective decisions may be evident everywhere, since the primary goal of all of these actions is to ensure the community's survival and progress.
Many concerns remain unanswered, including how competing interests and the sharing of distributed knowledge are reconciled in practice and should be reconciled in principle in order to foster collaboration and attain outcomes that match multiple ideal criteria. We can simply say that animal and insect collective decision-making research, as well as human collective decision-making studies, are only getting started.

1.1 Honey-Bee Communication and Decision-Making

The choosing of a nesting place by a swarm of up to 10,000 honey bees is a spectacular example of honey bee decision making [6]. This procedure entails hundreds of bees from the swarm working together to discover a dozen or more possible nesting holes on trees and then choosing the best one. In the late centuries, beekeepers have observed that a strong colony of bees will divide itself in late spring or early summer by "swarming", a process in which the queen and roughly half of the worker bees leave their hive to start a new colony, while a daughter queen and the remaining workers stay behind to continue the old colony.
In one of the research that looked at bees' collective decision-making mechanism [7], it was reinformed that the bees influence each other's decisions and communicate with each other via "waggle" . Waggling is a dance-like action that honey bees use to communicate (Figure: 1). Waggling contains a variety of factors such as angle and length. Its length denotes the possible nest's quality, and its angle shows the potential nest's direction. After returning to a certain location, scout honey bees promote the nest sites they find in this manner.
Honey bees that are waiting in the colony or have already left for different nesting places begin their

[1]the Kyoto Protocol operationalizes the United Nations Framework Convention on Climate Change by committing industrialized countries and economies in transition to limit and reduce greenhouse gases (GHG) emissions in accordance with agreed individual targets

[2]The highest level of organization of sociality.

own waggles. They demonstrate the length and angle variables we discussed and discuss the proposed site with other bees. Even though the waggles of honey bees examining only one possible site are short at the start, as they gain information about various locations, their distinct ideas begin to form [5]. They can get a 95 percent consensus on the ideal nest this way [8] while deciding collectively. Simply put, a majority voting mechanism is used, but because the advertising locations and honey bees are so reliable, finding the optimal nesting area with this voting approach is not difficult.

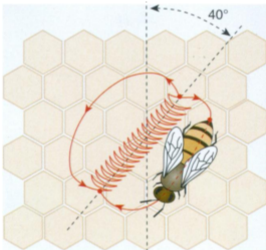

Figure 1: Honey Bee Waggle Rotation and Movements (Picture taken from: S. Camazine, P. K. Visscher, J. Finley, and R. S. Vetter.) [5])

1.2 Voting Methods and Liquid Democracy Adaptation

A voting system is a collection of rules that govern how elections are held and the outcomes of such elections. These rules govern all aspects of the voting process, including when elections are held, who is allowed to vote, who is allowed to run for office, how ballots are marked and cast, how ballots are counted, how votes are translated into election results, campaign spending limits, and other factors that can influence the outcome. Every day and at every instant, we employ a variety of voting systems, such as majority and plurality. In this study, the majority refers to when the person with the most votes wins, and the Borda Count refers to when each candidate is assigned a number of points for each ballot based on the number of candidates rated below.

The Liquid Democracy is a novel technique of voting that has recently evolved and, in some ways, is a kind of collective decision-making that falls between direct and representative democracy [9]. Each agent can cast his or her own vote on each topic put to a vote, or it can delegate its vote to another agent as a proxy, who can then delegate to still another agent, and so on. The agents who choose not to delegate their votes cast ballots, but their votes now have a weight equal to the number of agents who authorized them with their vote, either directly or indirectly.

1.3 Plans for Research

The model we'll build for this study will be based on real-life honey bee behaviours, and we'll first try to make [8] function in our own model before making adjustments to honey bee collective decision-making methods. The majority voting system utilized by honey bees has been found to locate the best acceptable nest location with a high consensus rate, as described in the Introduction section. Will voting systems that have evolved throughout human history and the liquid democracy method, which has lately gained traction, produce different outcomes in honeybees? Alternatively, will other voting techniques such as dictatorship or the Borda count increase the chances of honey bees picking the most suited nest? These are the concerns to which we are seeking explanations in our research, as well as the points to which we are attempting to bring alternative points of view.

2 Background Literature

As we mentioned in the Introduction chapter, these fascinating honey bee movements were discovered and studied a couple decades ago, in 1973, by the Austrian scientist Karl von Frisch. Our goal in this chapter is to provide insight into the subject we'll be covering by using the facts we'll provide from these previously written articles. In the first half of this chapter, we'll go over the specifics of the bees' motions, and in the second, we'll go over the voting techniques we'll employ, as well as the criteria and how they apply to our project.

2.1 Dance of Honey Bees and Consensus

Martin Lindauer originally indicated that these honey bee dances and creating a voting group were genuine procedures in his publication in 1950. The nuances of this technique are almost as fascinating as the process itself. When a nest region becomes useless or the colony becomes large enough, the queen bee and various groups of scout honey bees hunt for a new colony, allowing the queen bee to stay at the nest. During this stage, which lasts around one or two days, these dispersed groups of bees fly to probable nest locations at regular intervals and make their own assessments. At the end of this procedure, each of the honey bee scout groups will have a good understanding of where the best nest location is and will have completed the advertising plan. Following that, groups of honey bee scouts begin to dance about their proposed nest, with each dancing bee acting as a vote. While performing their own dance, honey bees also analyze the dances of other bees, speeding up the voting and decision-making process. Figure 3 illustrates this concept (taken from Camazine et. al. [5]). The bees' agreement on two separate nesting places is presented. While the two suggested nest locations expand and gather votes on a regular basis, the better (West box) nest site eventually draws the attention of the whole colony and guarantees that the votes are collected. The relocation, or Take-Off, occurs whenever a particular amount of votes are obtained.

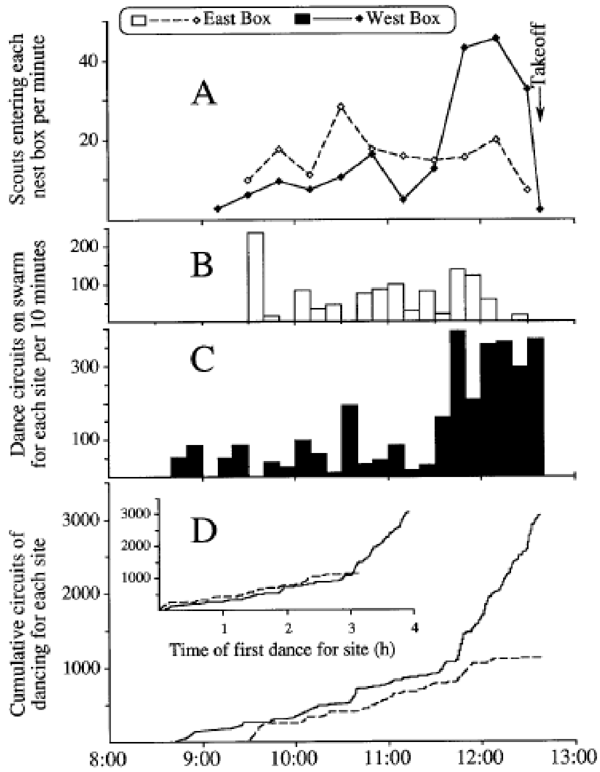

Figure 2: Illustration from Camazine et. al. House Hunting (1999) [5]. The process of honey bees developing a consensus on two acceptable nest sites (West and East Box) is depicted in this diagram. After evaluating the information for a length of time, scout honey bees form a voting group for the best nesting site and then take off.

The goal of the model we'll try to construct is to imitate bee behavior, such as seeking nesting places and casting votes. We will model characteristics that may be realistic in these simulations, such as reliability, interdependence, and the possibility of obtaining and assessing information on a site.

2.2 Bee voting methods and Liquid Democracy

Honeybees employ the majority voting mechanism to make their judgments, as we previously said. The bees had more than one "voting state" while this voting community was being developed, according to L. Condrat's [10] article. Honeybees have three voting states, as shown in figure 3, in this study, and when deciding between two nest locations, they can vote for site A, vote for site B, or not vote at all. These criteria will be included in the model we develop, as well as aspects such as dependability, interdependence, and independence indicated in the C. List's [8] article. The criteria of reliability and independence/ interdependence that we described are defined as factors that influence honey bee votes with a high likelihood. This strategy worked well for our model and inspired the study's next phase, which involves the introduction of novel voting systems to honeybees. One of the new voting mechanisms, dictatorship, is similar to the one employed by honeybees, and as we move closer to an agreement, we observe a voting mechanism that becomes a dictatorship. We will take the queen bee's choice and utilize it in the dictatorial voting technique that we will introduce. Then, using the Instant-runoff voting system, we'll look at a situation in which honey bees are removed based on the lowest number of votes. Finally, we will apply the Liquid Democracy technique, which has lately gained popularity, to our work and evaluate the outcomes.

2.2.1 Liquid democracy

Liquid democracy is a contemporary voting method in which citizens can vote directly or delegate their vote to other voters. Despite the fact that this is the primary definition of the shape we will use in the project, the key innovation underlying liquid democracy is that proxies who were chosen by voters to vote on their behalf may delegate their own vote to a proxy, and in doing so, further delegate all of the votes entrusted to them.
In the Christoff and D. Grossi [9] study, they discussed the limitations of liquid democracy and how it may be improved which is the major source of our thinking, and describes the 'Liquid Democracy' voting system. Although we will adapt Liquid Democracy's fundamental logic to our model as follows: binary aggregation with abstentions, the full capacity utilization of Liquid Democracy remains a bit complicated for our current project.

A binary aggregation structure (BA structure) is a tuple $\mathcal{A} = \langle N, \mathbf{P}, \gamma i \rangle$ where:
N = $\{1, ..., n\}$ is a non-empty finite set individuals (| N | = n);
P = $\{p_1, ..., p_m\}$ is a non-empty finite set of issues or propositions (| P | = m);
$\gamma \in$ L is an (integrity) constraint, where L is the propositional language constructed by closing P under a functionally complete set of Boolean connectives. [3]

A binary opinion is a set of issues **P** to which acceptance/rejection values (or truth values) are assigned. Allowing abstention requires consideration of a number partial opinions: a partial function from **P** to $\{0, 1\}$ is an incomplete opinion. We'll look at it as a function $O : \mathbf{P} \Rightarrow \{0, 1, *\}$ with the indeterminate value "$*$" corresponding to abstention, precisely denoted [9]. These rules will be the foundation of Liquid Democracy, which we will include in our model within the scope of the above-mentioned regulations. With a predetermined chance, each honeybee will be able to transfer its voting privileges to another honeybee companion. It has the option of casting its own vote or not voting at all, in addition to renouncing its voting power.

[3] Set of rules are taken from Z. Christoff and D. Grossi [9].

3 Methods

Experiments with insects, which have been carried out in recent history, have brought with them a number of obstacles. In greater detail, in research on honey bees, the queen bee's directives, the likeness of the bees to one another, and the continually changing colony structure are among the elements that heighten the challenges. After briefly discussing how the earlier research that inspired this study carried out these experiments, we will discuss the adaptation of these experiments to our work, and finally the model, in this part.

3.1 How are honey bee colony studies conducted?

We begin with T. D. Seeley [6], the first research we used as an example was conducted in real-world situations, which adds a unique viewpoint to this topic. "How do honey bees find new homes?" This was the question posed at the start of the investigation. This inquiry begins with the search for the proper bee colony. It was determined whether the colony discovered originally had the following characteristics: whether there are enough honey bees; whether a queen bee exists, and whether a nest change will be necessary for the near future.

Following that, there is a honey bee colony of roughly 4000 bees, which makes this study unique, and each bee is marked one by one. This marking enables them to track each honey bee's movements. Tracking the honey bee colony's movements reveals which groups the honey bees belong to over time, such as worker bees or scout bees. By installing observers at the proper nest sites within the experimental setting, this experimental team had the chance to analyze which bees travel back and forth, as well as the behaviors of the roaming scout bees once they return to their homes[4].
They next examined each scout bee's motions and documented the length of their "waggle" movement, its influence on other bees, and its intensity.

Figure 3: Picture taken from Seeley [6], individual honeybees are labeled with colored plastic tags affixed to their body, with their colors designating groups such as scout bees, worker bees, breeder bees. These markings allow investigators to distinguish between individual scout bees when observing a swarm's behaviour.

C. List' work [8], which is the primary source of this study, is the second research technique example. This is a model-based study, and researchers have modified and exploited real-life variables, such as reliability and interdependence aspects, to their own situations. This investigation did not necessitate the use of the personnel necessary in the prior Seeley's study [6]. The researchers assumed the colony had 250 scout bees, split them into five groups, replicated their behavior, and then examined the data they collected. They subjected the honey bees' behavior and decisions to several elements in the data they got subsequently. When the independence factor

[4] Experiment conducted in Appledore Island

is between 0 and 1, the bee indicates that when the independence factor is 1, the bee will listen to its own vote and will not vote for the appropriate nest locations told by other bees. Alternatively, interdependence was identified as a factor influencing how much a honey bee trusts other bees, even if it does not travel.

3.2 Simulation Environment and Task Description

In the following sections, we will give a model-based analysis based on the second case from our research. The phases of the approaches we will utilize to get the study's outcomes are as follows:

The total number of scout honey bees, as well as their behaviors.

Determining factors, dependability, independence, and so on, as well as their formulation.

Liquid democracy and alternative voting procedures adaptation.

Making a statistical model in the generated model, and then modifying and re-applying the numbers that started the experiment, so that we can see the behavior in other numbers and the data can be checked accurately again.

Before we describe their formalized form in the following chapter, we'd want to go through the many interesting things we are modifying in this research. In this system, where each honey bee is monitored independently, we built a method in which the scout honey bee would return to the nest every 5 turns and notify us about its ideas as soon as they are generated. Each honey bee is born in the same time unit and is exposed to a voting mechanism based on the ultimate choice made after 15 rounds. The voting method employed in this study is a voting system we issued or the natural voting system. Because the time in the simulation environment we developed is turn-based, we can always see the behavior of each honey bee during its cycles. For example, we can observe the transformation of the bee's idea in the 4th time turn and 5th time turn. This also supplied us with a distinct perspective when doing the study and increased the inspection of the simulation.

4 Experimental Setup

In this chapter, we will go through the specifics of the tests we ran, how they were carried out, and what we utilized. Furthermore, this section, in which we will present the simple results we have acquired, will make our research more understandable and in-depth. After discussing the explanation of the findings of the previous chapters' investigations and scratching the surface, it will be clearer to comprehend these concerns and what we intend to alter and what we will change.

4.1 Tools and Environment Configurations

The study's coding environment was primarily Python, the Windows 10 Educational 64 bit operating system was employed, and the data were then exposed to the models we generated in R for model and accuracy. In addition to the above, the computer characteristics employed in the studies include AMD Ryzen 5 2600, 16 GB RAM, and an NVDIA Geforce GTX 1060 graphics card.

We may begin to describe the circumstances and formulae we have adjusted by doing the following. There are 250 bees in the universe in which we produced the simulation in the first place; this is to evaluate the correctness of our study's data and to check if the findings we have obtained are close to a bit; it is an element that offers us robustness in the first place.
If the worth of each bee's voting rights is equated with each other, and there are two or more acceptable settlement places, we may assert the following:

In our voting system, every two voters play equal roles.;

The rule treats each of the two possibilities equally.;

Honey bee voting occurs when a group of bees casts votes that serve as the foundation for a collective decision achieved via the application of a voting rule. A multitude of voting settings are available, based on the defined form of a ballot and a collective decision, as well as the interpretation we choose to make of these forms; the phrase "voting rule" is broad, including all possibilities. Our primary focus will be on one type of social choice function that employs ranked ballots and general notations such as transitivity:

N = $\{1,...,n\}$ is a non-empty finite set of bees, initial step with n = 250 ($|N|$ = n);

A = $\{1,...,m\}$ is a non-empty finite set of candidates or suitable bee nests ($m \geq 2$) initial step with m = 5;

The ballot cast by the bee i is a linear ordering $\succeq_i$ of A: transitive, complete, reflexive.

A profile P = $(\succeq_1, \succeq_2, ..., \succeq_n)$ specifies such a ballot for each voter i $\in N; L(A)^n$ indicates the collection of all such profiles for any given n, and $L(A)^{<\infty}$ stands for $U_n \in_N L(A)^n$ (where N denotes the set of all natural numbers).

We are interpreting these general frameworks from our guidebook, which was authored by William S. [11]. Because of preferred interpretation, this set of principles allows us to characterize such votes as preference rankings: bee i's (strict) preference for choice X over alternative Y is expressed as $x \prec y$.

Aside from the equal validity of the honey bees' votes, the elements that influence each bee's decision and the aspects that are real-life considerations are crucial in a bee's ultimate decision. A bee's choice is recorded every time it takes its turn, as shown in the Figure 4, and it is subjected to various circumstances before making this conclusion. As soon as the honeybee is produced (which is also the period of creation for all honey bees), $\Delta_{Chanceoffind}$ begins with a chance to locate a new nest or migrate from where it is with a predefined ratio in between 0.25-1.00. The reason this ratio starts with a low value is that there are natural obstacles that prohibit honey bees from reaching their hives or new locations or retaining them where they are, such as weather conditions, animals, and so on. This $\Delta_{Chanceoffind}$ ratio prohibits them from continually discovering new appropriate locations and reliably arriving at the optimum nest site. If the honey bee does not have a choice, nest site selection is the first thing it registers when it comes to a possible nest.

Each nest location has distinct characteristics, which we may describe as follows: security, distance, quality, and size (See also Figure: 5). These parameters are multiplied by the $\Delta_{DegreeofAssessment}$ multiplier of each bee found in that experiment, and the result is the interpretation of that bee for the suitable nest site, namely the "waggle." When a bee distinct to each bee is formed, a $\Delta_{DegreeofAssessment}$ in the range of 0.99-1.00 is created.

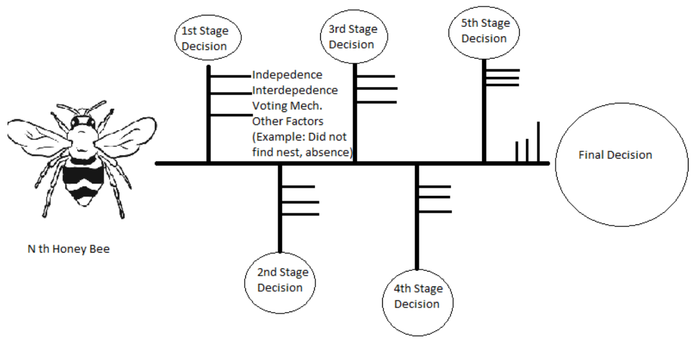

Figure 4: Only one bee figure from each bee formed in time period 0 is presented. The decision made at each time period is noted in this bee's 5-stage evolution. At the same time, when making this decision, it is subject to variables such as independence or other circumstances. The sixth time slot, whose final decision is not represented in the picture, is gathered and moved to the preference declaration time, when their selections are recorded. The values of these parameters range from 0.00 to 1.00, influencing and altering the decisions of each honey bee from the beginning to the conclusion.

Unlike these, the causes of not trusting other bees, notably $\Delta_{Indepedence}$ and $\Delta_{Interdepedence}$, come into play at the gathering time stage, that is, in the last stage, while everyone is conducting their own dance. These variables change depending on the experiment, and their ratios range from 0.00 to 1.00. When it is 0, it does not trust other bees and just listens to its own choice; when it is 1, it listens to the decisions of the honey bees it acknowledges rather than its own. With a value of 0.60 in the remaining interval, for example, it accepts the other bee's judgment with 60% probability and votes for that region.

During these five-time stages, the honey bee may recall the best nest site it has found for itself, compare it to the nest site it is now in, and record the spot as the best if it is better than the prior best nest site. Finally, at stage 6, each bee creates the finest nest site advertisement that it can discover for itself, and a common choice begins to form in all bees. During this period, the bees are influencing and instilling their thoughts in one another. This procedure differs depending on the voting mechanism employed in the experiment. In the liquid democracy technique, for example, they vote in turns, beginning with the first honey bee and finishing with the N_{last} honey bee, or they have a choice between transferring their voting rights or keeping their voting rights and voting when $N_{Current}$ bee has the turn.

When it comes to voting procedures, we will employ Borda Count and Liquid Democracy modifications in addition to the majority voting rule. We construct a Profile **P** for every Nth honey bee, which we will utilize in the Borda Count, and register it in a system where we vote on the honey bee's prospective nest site choices. While extensive information on how the Borda Count works is available in Brant. et .al [11], the portion we will contribute to our study is as follows: Every Nth honey bee arranges the possible nest site quality order list in the last time stage; this is also the honey bee's ballot **P** and votes in that order[5].

The major source of the technique we use in the implementation of the Liquid Democracy method is in Khang et. al.[12], and we apply it by adjusting its logic to the problem addressed in the study. We presume that the honey bees are voting on a binary issue with a valid and incorrect choice. Each honey bee voter $i \in$ A is identified by its degree of competence P_i. This is the likelihood that i holds the proper view on the subject at hand, i. e. , the likelihood that it will vote correctly on the best potential hive. We define a voter approval relationship as follows: If $i\,j \in$ and $P_j > P_i + \alpha$, $i \in A$ approves $j \in A$. In other words, if the gap in *approval rate* is least α difference in between and i approves it neighbor j[6].

The last voting technique we will discuss is the Majority voting rule, and as the name implies, the preference for the j nest location in group A, where every third honey bee decides, is its ballot, and the voting is constructed if it is utilized in this manner. The key reason for using this voting technique was to verify its robustness with past research as the initial step in our experiment's development.

4.1.1 Tied outcomes and Special Cases

There is always the chance of a draw outcome in scenarios with several victors. There are several winning situations in our instance, but we chose to design specific circumstances to break them.
Bubboloni et. al.[13] and Elkind et. al. [14] are two studies used as examples. While this has been shown to be the most probable accurate choice in these researches above([14], [13]) there is something more appropriate that we may utilize in our investigation. In this situation, the queen bee, the specific condition of our study, and the queen bee with a tie-breaker function will be used as the deciding element in the event of a tie. Its goal is to solve draws in the same manner as the Borda Count voting technique and Liquid Democracy voting method do. In addition, there is a manual review, albeit a review, after each simulation to see if there are any errors or special cases.

[5]The first option receives the most points, while the last option receives the fewest. The potential nest location with the highest score is selected.

[6]$\alpha > 0$

4.2 Performance Criteria

Our work includes more than one performance criterion or aspect that tests the simulation's realism. The performance requirement of the real-world research, Seeley et. al. [6], was the consensus of a honeybee hive to take action, but in the study of Camazine et. al. [5], this was artificially given and $L_{liftoff}$ was greater than 95%. This ratio served as a guide for us as we tested the validity of our research.

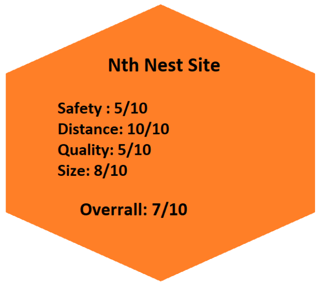

Figure 5: One of the prospective nesting places has been depicted. Each nest location has its own set of four randomly generated values. These four values are as follows: safety, distance, quality, and size. Finally, the four values are added together and averaged. This total value is then averaged to generate a quality score for the Nth nest site. This value is then held in reserve to be multiplied by the Nth bee's $\Delta_{DegreeofAssessment}$.

4.3 Mechanisms of Influence and Uncertainty

Honey bees in our experiments needed to be influenced in some way in order to abandon their decision. Independence and interdependence factors are effective in this influence mechanism. While the $\Delta_{Indepedence}$ rate determined in the simulation, indicates the rate at which they listen to their own ideas, we can also say that the $\Delta_{Interdepence}$ rate is the rate of honey bees influencing one another. The higher $\Delta_{Interdepence}$ rate, the greater the chance of being influenced by a more qualified hive promoted by another bee.

We tried to leave a 0.01 uncertainty at each determined ratio in the uncertainty situations. It has been left as a ratio to add realism to the experiments, as some bees will behave differently, disappear, or simply behave differently than expected in real life conditions.

5 Experiment Results and Evaluation

The sections we will discuss in this chapter are as follows: first, we will show you how we discovered the results in an example experimental scenario and what these findings are; and then we will show you the results of the simulations we ran using different voting techniques. Finally, we will attempt to demonstrate how simulations become normalized after iterations.

5.1 Example Case

For the example case, we chose a simple scenario for ease of reading and comprehension. There are 250 scout honey bees in total, with N = 250. There are eight potential hives, with the values $A_{1,2,3,4..8}$= 5, 6, 5, 4, 3, 7, 8, 5, 4[7]. Among the factors influencing honey bee selection, $\Delta_{Chanceoffind}$ = 0.10 represents a scenario in which honey bees find a relatively rare potential area, and $\Delta_{Reliability}$ =0.9, implying that they will persuade 9 out of every 10 bees to show their opinions.

The $\Delta_{Indepedence}$ is 0, and it is fully tuned to fully trust what other bees find, resulting in a higher level of consensus in our exemplary scenario. Figure 6 depicts a visit to the region during each time period. This distribution is a random distribution that is influenced by $\Delta_{Chanceoffind}$. In the continuation of Figure 6, Figure 7, after the given time has passed, the votes cast are shown in order for $A_{1,2,3,4,5,6,8}$; they are 12, 20, 6, 3, 3, 10, 193, 3. Assuming the queen bee voted for the highest nest point, consensus was achieved with 77.2 percent, and the best nest site was chosen. The effect of voting style and the best nest site determination rates, as well as the factors that influence this rate, will be discussed in the following sections of this chapter.

5.2 Majority Voting

In our first ten simulations, we see the average consensus of simulations without changing any factors, i.e. by leaving everything as is. The first ten simulations used a high level of $\Delta_{ChanceofFind}$, ranging from 0.99 to 9.90. Furthermore, low $\Delta_{Indepedence}$ of 0.25 and normal $\Delta_{Interdepence}$ of 0.75 were used. The values used in these ten simulations are chosen to facilitate further interpretation and to determine how much the consensus values will change when the simulations begin.
The results in these 10 simulations are as follows; consensus with the majority voting method;$C_{1,2,3,4,5,6,8}$ 75, 79, 75, 78, 84, 76, 68, 79, 80, 77[8] and the average of all of the consensus found was 77.53; they found the best potential hive. With the $\Delta_{ChanceofFind}$ amount decreasing, a total of 2142 votes were cast in 10 simulations, and the vast majority always finds the best hive-site. The highest level of agreement was 84.87, while the lowest level of agreement was 68.83. In our next ten, three experiments, we'll change all of the factors that influence the consensus rate and define its consensus or the rate at which they find the best hive-site.
In our second ten-simulation, we keep the $\Delta_{Indepedence}$ factor very high (0.85-0.95) and the $\Delta_{Interdepence}$ factor very low (0.1-0.01). The effect on the honey bee colony is as follows: honeybees vote on potential nest sites that they visit and assign their own score. This means that the location where the majority of votes are gathered is directly proportional to where the honey bees are distributed. We leave the $\Delta_{Chanceoffind}$ factor alone and assume that they visit one potential site at a rate of 96 percent each turn. They are much lower than the percentage they reach consensus in our experiment, and

[7] At the start of the experiment, values were assigned at random.
[8] Floating numbers removed for better readability.

$C_{1,2,3,4,5,6,8}$ 36, 30, 29, 31, 35, 45, 31, 39, 37, 31[9] respectively. The average percentage of honey bees in consensus is 35.66 percent. Consensus, which reached 75% in our previous simulation of ten, dropped to 35% in this simulation, often. Despite these low consensus rates, they were able to identify the best potential hives. This is because, after five rounds, at least some of the scout bee members visit the best potential hive, forget about the potential hives they saw in previous rounds, and vote for the best.

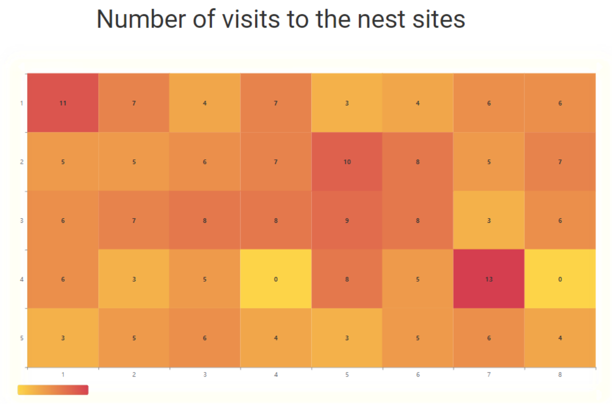

Figure 6: Random scatter of bees each turn

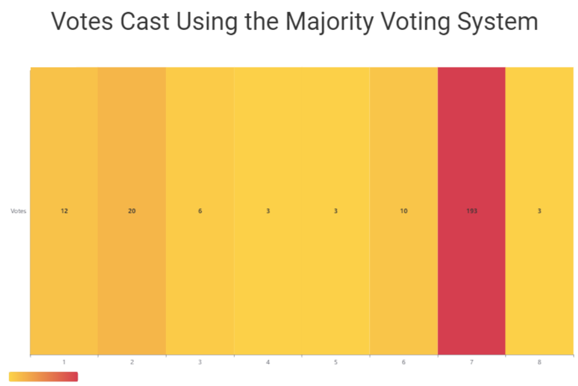

Figure 7: Vote distribution

We wanted to factor $\Delta_{Chanceoffind}$ to extreme conditions and see if they still found the best potential hive in our last ten simulations, where the rate of honey bees finding a new potential hive in each round. While in previous simulations, 200 to 249 honey bees found a hive point for each round, we reduced it to 20-49 honey bees found a hive point for each round, and we used low independence of 0.25 and normal interdependence of 0.75. In this experiment, we can see that the consensus was reached with much lower percentages than in the other 20 simulations, which are as follows: $C_{1,2,3,4,5,6,8}$ 28, 19, 27, 33, 18, 50, 24, 45, 20, 22[10]. In comparison to our other simulations, the average consensus percentage was 29.04 percent, and the rate of reaching the best hive was 80 percent, with two of them failing to detect the best.

5.2.1 Remarks on Majority Voting

The following are the functions and random placement methods that we use in our simulations: It arrives at a decision by comparing the best potential hive point in the bee's memory with the incoming offers and taking into account the factors listed above. In our second simulation, we look at a scenario series in which honeybees vote where they are most confident, and then a very few honeybees go to potential hive points and cast their votes with high honesty. In the final of these scenarios, when only a few honey bees discovered a new location, they failed to select the best location between the two scenarios.

[9]Floating numbers removed for better readability.
[10]Floating numbers removed for better readability.

5.3 Borda Count

We are changing the method of voting to select the best potential hive after staying as close to real life as we could in previous parts of our experiments. While honey bees always remember the best place they've seen, in this part of our experiment, they create their own preference list and vote based on it (See Figure 8). We will give honey bees the right to rank the alternatives $A_1, A_2, A_3..A_m$ as $A_{\sigma(1)} \succ A_{\sigma(2)} \succ .. \succ A_{\sigma(m)}$, $A_{\sigma(1)}$ gets m-1 Borda points, $A_{\sigma(2)}$ gets m-2 Borda points, ..., $A_{\sigma(m)}$ gets 0 Borda points. A given alternative's Borda score A is the total number of Borda points awarded to A by the voters. By comparing the Borda scores of the various alternatives, the social ranking of the alternatives and the winner(s) are determined [15]. Although there are multiple ways to break a tie depending on the case, the queen bee's vote will be used as a tie-breaker in this study. In the event of a tie, the queen bee is determined to cast her vote at random on one of the two best options. We will explain how the Borda Count voting method works in the example case, as well as the scenario simulations that we discussed in the Borda Count conclusion section.

5.3.1 Example Case for Borda Count

Site Number	Bee Group 1	Bee Group 2	Bee Group 3	Total
1	3	3	0	6
2	2	2	3	7
3	1	1	2	4
4	0	0	1	1

Table 1: Example Case for Borda Count, winner site 2 by 1 points.

Table 1 shows nest site preference lists based on four potential sites visited by three bee groups ($C_{(1),(2),(3)}$). Scout bee group 1 made a list of <1, 2, 3, 4>, Scout bee group 2 made a list of <1, 2, 3, 4>, and Scout bee group 3 made a list of <2, 3, 4, 1>. According to these, $A_{\sigma(1)}$ gets six points, $A_{\sigma(2)}$ gets eight points, $A_{\sigma(3)}$ gets four points, and $A_{\sigma(4)}$ gets one point and $A_{\sigma(2)}$ wins.

We can see that the third bee group may not visit the best nest site, or it may have a miscarriage in its own assessment, which affects the outcome.

Scout Bee Group	Preference list
1	$< 5, 3, 2, 1, 4 >$
2	$< 5, 3, 2, 1, 4 >$
3	$< 5, 3, 2, 1, 4 >$
4	$< 5, 2, 4, 3, 1 >$
5	$< 5, 2, 4, 3, 1 >$
6	$< 5, 3, 2, 4, 1 >$
7	$< 5, 2, 4, 3, 1 >$
8	$< 5, 2, 4, 3, 1 >$
9	$< 5, 3, 2, 1, 4 >$
10	$< 5, 2, 4, 3, 1 >$

Figure 8: Example table of Scout Bee Group's Preference Table

The Borda Count voting method will consider three different scenarios, and the percentage of consensus reached and the percentage of best nest sites will be examined in each scenario. The following are the three scenarios. In the first scenario, bee groups will have two preferences; in the second scenario, bee groups will have five preferences, and finally, not as groups of bees, but with each individual bee having two preferences, will be discussed.

In our first scenario, there are 5 bee groups in total, with each group consisting of 50 bees. Each bee group assigns its own group score based on the locations they visited in five-time stages and the $\Delta_{ChanceofFind}$. When it comes time to vote, the bee group evaluates the regions, visits, and presents its own preference list. Each of the five honey bee groups has two preferences. In ten experiments, the rate of finding the potential hive with the highest score for one bee group was 0.63, always within the scope of moving to a different site in the stage. In four of the ten simulations, they failed to find the potential hive with the highest score, but they did find the hive with the highest score in six of them. At this rate, which reached 60%, the hive point with the highest score was determined to be the first choice at 58.1 percent.

In our second scenario's ten simulations, unlike the previous one, honey bee groups have five preferences rather than two. In this simulation, we observed the effect of this in the Borda Count voting method, as it is seen that the lower preferences funnel their votes from the upper preferences. They found the second-best point in six of the ten simulations, the best point in three, and the third-best point in one. We can see that doing so reduces the rate of finding the best by up to 30%. We can see that, while the second-best hive point received a majority of votes, it received 10% -20% more Board Points than the option below. The best hive point was visited in scenarios with the second-best potential hive, but it did not collect enough points in the preference list. We discovered that a large number of honey bees who voted for the best site were funneled to the options below or the second-best spot. One reason for the slight difference between the first and second-best spots is that we simulated honeybees visiting a site in groups of 50 honeybees and gave their preference lists in groups of 50 honeybees.

In our third and final 10 Borda Count simulation scenario, we randomly assigned 250 honey bees to our five-time stages without grouping the honey bees. We collect a preference list with two options from all 250 honey bees at the end of the five-time stages and then assign a score using the Borda Voting method. In nine of ten simulations, the bees found the best hive point, and in one, they found the second-best hive point. This increases the likelihood of locating the best potential point by up to 90%. The difference between the voting point and the losing election point is between 20 and 40 points, and the best point wins. The difference in points in our scenario where the best point loses was 8. The reason for finding the best potential hive point of up to 90% is that the probability of the best hive point coinciding with a honeybee in one of the five-time stages is high, and on top of that, after visiting the best spot, the points are not distributed enough to other options and remain at the best spot.

5.3.2 Remarks on Borda Count Voting Method

The reason why the average of finding the best hive point in the scenarios varies so much is that as the given list lengthens, the lower hive points gain useless points, preventing the selection of the best spot. In some cases, the honey bee that visited both the first and second-best spots cast the second preference vote, which resulted in the selection of the second-best hive location. When each honey bee specifies a preference list with two options, the probability of visiting the best spot increases dramatically, and the majority of points are concentrated on the first spot, with a margin of votes of about 10%.

5.4 Liquid Democracy

Liquid democracy is a collective decision-making procedure that combines direct democratic participation with a flexible representation account. Its basic model is made up of four components[16], which are as follows: All members of a political community who meet a set of reasonable participation criteria have the right to:

Vote directly on all policy issues;

Delegate their votes to a representative to vote on their behalf on a single policy issue.

Delegate those votes received through delegation to another representative;

Terminate the delegation of their votes at any time.

Although this terminology contains elements of Liquid Democracy, we must devise a suitable method for the work we do, and we do so as follows: each honey bee can vote directly on all hive points, delegate their votes to a representative to vote on their behalf, delegate those votes received through delegation to another representative, and finally, unlike the preceding list, the votes cast are irrevocable.
In our simulations, the honey bees have the following options in each round: use the voting right to a random option, delegate the right to vote, or pass that round. The actions indicated correspond to the endomap in Figure 9. While some of these movements, such as the right to pass or delegate, may have a continuation, the vote, on the other hand, does not.

Because the delegation of voting rights is what distinguishes the Liquid Democracy voting method, we begin by including $\Delta_{RateofDelegate}$ in our simulations and determining its degrees between 0.0 and 1.0. The $\Delta_{RateofDelegate}$ indicates the likelihood that a honey bee will delegate the right to vote. The $\Delta_{RateofDelegate}$ was kept low (0.25) in the first ten simulations, moderate (0.50) in the next ten, and high (0.75) in the last ten, and the results were compared. The probability of the honey bee's movements can also be written as follows; the action each honeybee will take per round is $\Delta_{RateofDelegate}$, 0.10 chance to pass the round (*PR*), and $\Delta_{RateofDelegate}$ - *PR*, which gives us the $\Delta_{RateofVote}$. In the simulations, three honey bees are pre-delegated to potential hives. These three bees were nominated as delegate candidates for their assigned points. Their goal is to pretend that the potential spot has the highest score and to be a candidate to whom other honey bees can delegate voting rights when other honey bees delegate voting rights. If 5% (12) of the total number of bees remain and the delegate or pass continues, the voting ends.

5.4.1 Example Case for Liquid Democracy

In this section, we will explain our sample scenario and how we arrived at our conclusion, followed by a presentation of the results. The $\Delta_{RateofDelegate}$ used in the case study is low (0.25), and the voting rate is set high for simplicity and to complete in short time stages. In this scenario, our 250 bees and three delegates are chosen at random. The potential hive quality was determined at random and is as follows: $PS_{1,2,3,4,5,6,7,8}$ $QP_{8,3,7,2,1,6,4,5}$[11]. Potential sites 1–3-5 will be promoted by our delegates. There were 183 votes cast in the first round, with 20 preferring to skip the round of honeybees and 47 delegating the right to vote. 14 of the delegated votes were distributed at random to the first region, 21 to the third region, and 12 to the fifth region. The first and fifth hive point delegates preferred to use their votes for their own points in the second round, while the third hive point decided to delegate their voting rights and passed their votes to 5. Finally, the power of the first hive delegate was 14 votes, and the power of the fifth hive delegate was 33 votes. $PS_{1,2,3,4,5,6,7,8}$ $LDP_{37,30,27,29,56,30,20,21}$[12] $PS_{(5)}$ is chosen as the next hive point with a consensus of 22.4 percent and a vote rating of 56. Although $PS_{(1)}$ is the best hive point, we can see that it is directly related to the transferred votes, winning according to LDP score and vote coefficient totals.

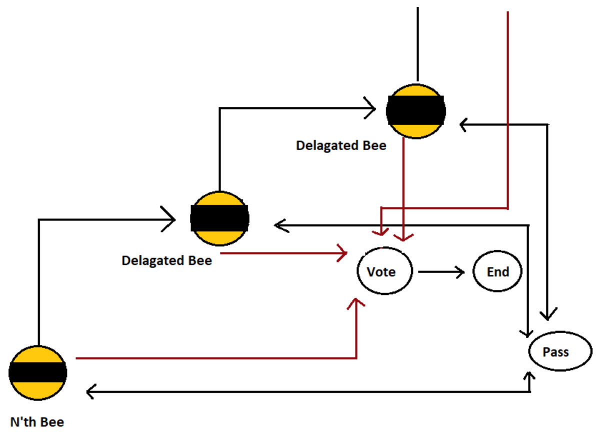

Figure 9: Endomap of Bee actions; N'th bee can vote, pass or delegate. Vote action has no continuation, pass and delegate has continuation.

$\Delta_{RateofDelegate}$ was kept at 0.25 in the first ten simulations, $\Delta_{RateofVote}$ at 0.65, and $\Delta_{RateofPass}$ at 0.10. In the studies, the best hive point was discovered three times, the second-best hive point was discovered twice, and no high-quality point was discovered five times. The average of finding the point with the highest score remains at 30%, and the consensus rates are $CR_{28,29,40,26,20,22,30,36,30,40}$ on average, the consensus was achieved with 33,875%. We discovered that when votes with a high percentage (0.65 VR, 0.10PR) were randomly distributed, all potential points remained evenly distributed until the delegates' votes were counted. The coefficients of the delegates' votes ensure that the majority of the votes are replaced in subsequent rounds. In our next scenario, we will gradually increase the delegated rate and discuss how this affects votes.

In our second 10-second simulation, $\Delta_{RateofDelegate}$ was increased by 0.25 to 0.50, $\Delta_{RateofVote}$ was reduced to 0.40, and the $\Delta_{RateofPass}$ remained constant at 0.10. This shift was reflected in the results, which are as follows: as the rate of delegation increases, the delegates' votes become the majority and determine the winner. The final vote, which went back and forth among the candidates, found the best potential hive with 20%, the second best site with 40%, and one of the sites with insufficient points in the remaining 40%. In ten simulations, consensus was ranked as follows: $CR_{18,19,14,20,12,11,16,16,25,23}$, with the average consensus being 14.4 percent.

[11] P.S. stands for:Potential Site, Q.P stands for Quality Points
[12] LDP stands for Liquid Democracy Points

In our final ten simulations, we increased the delegate ratio from 0.50 to 0.75 to our highest setting, which means that nearly three out of every four bees give their vote to one of the delegates. In this experiment often, the best site was chosen in three of them; the third-best site point was chosen in four, and a nest site that did not have a significant score in the remaining three was chosen. In ten simulations, consensus was ranked as follows: $CR_{8,11,6,14,6,14,12,12,13,10}$, with the average consensus being 10.6 percent. In these simulations, we achieved the lowest consensus rate.

5.4.2 Remarks on Liquid Democracy Voting Method

The liquid democracy voting method is still very new and developing, with real-world applications in some studies, but in order to simulate bee behavior, we had to set different rules. These various rules are added to end voting and exercise or delegate voting rights, rather than prevent them from doing so. The reason for the constant decrease in the consensus rates we obtained in the simulations was as follows: after using some of the votes they obtained, the delegates distributed the rest to the other delegate and repeated this move with other delegates, both lengthening the number of rounds and decreasing the percentage of bees reaching consensus.

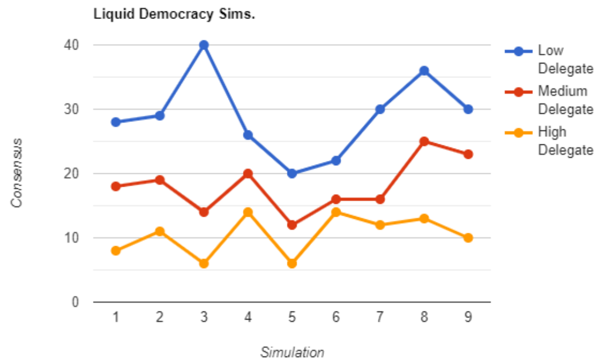

Figure 10: Liquid Democracy Consensus Rates Compared to Simulations

5.5 Comparison of Consensus Rates of Voting Methods

We will compare the results of the voting methods we used, namely consensus rate and whether they have found the best potential hive point, in the final section of our results (Figure:11). The majority voting method's consensus rates are gathered at a higher rate than other voting methods, as shown in Figure 11. As previously stated, the high consensus rate of the Majority voting method is due to honey bees' high reliability, and the consensus is easier to achieve because the quality of the hive point that is determined to be the best can be proven with ”waggles.”

Although there are high consensus rates on the Borda Count method, there are times when the second-best hive point is chosen. This, we believe, is due to the fact that bees who voted for the best nest site distributed their points to the second hive point. We can say that the second-best point stole points from the first in this case. We observed a change of up to 10% in consensus rate of bee groups with 5 or 2 preferences in the experiments we conducted within the category of the Borda Count method, but consensus amount decreased to the minimum when the honey bees made an individual preference (Figure:13). The reason for the decrease in this consensus rate is that honey bees' 2-preference list scores are nearly evenly distributed across all possible points. The winner in this even distribution is either the best or second-best spot.

We can discuss the results of the Liquid Democracy voting method experiment series: Using the Liquid Democracy voting method, we identified three advertised points to which our honeybees will delegate their votes, giving honeybees a reason to do so. Even though two of these three points are fake, one is chosen as the best hive point. Honey bees take turns performing one of the actions that they are familiar with. When less than 5% of the voting rights remain in the honey bee hive, the voting process ends. We observed how increasing the delegate ratio affects the rate of consensus in the benchmarks we tested (Figure: 10). In our experiments with a high delegate ratio, we discovered that consensus rates dropped to 10%. We found that in experiments with a low delegate ratio, the amount of consensus was 20% higher than in experiments with a high delegate ratio. We believe the main reason for this is due to the way we conducted our experiment. Honeybees vote for the advertiser delegate in experiments with a low delegate ratio, but in experiments with a high delegate ratio, the honeybees constantly transfer their votes to another delegate, and the votes cast are evenly distributed among other points.

Finally, we'll summarise all of the voting methods and experiments we used in this chapter by listing the average consensus rates for each experiment category. The average consensus in the first series of experiments we conducted with majority voting was 77.53 percent, 68.83 percent in the second series of experiments, and 35 percent in the third series of experiments. Using the board count voting method, it was 38 percent in the first series of experiments, 29.46 percent in the second series of experiments, and 15 percent in the third series of experiments. In the first series of experiments using the liquid democracy voting method, 32 percent consensus was achieved, 24 percent in the second series, and 12 percent in the third series.

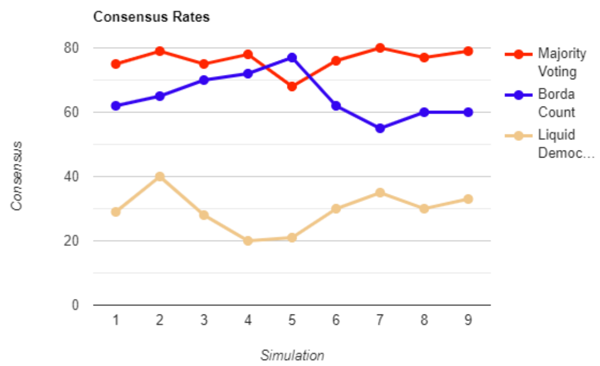

Figure 11: Consensus rates of the first trials of each voting method.

The following is a list of the average consensus amount:

Majority Voting 1 (77.53) > Majority Voting 2 (68.83) > Borda Count 1 (38) > Majority Voting 3 (35) > Liquid Democracy 1 (32) > Borda Count 2 (29.46) > Liquid Democracy 2 (24) > Borda Count 3 (15) > Liquid Democracy 3 (12)

6 Conclusions

The paper has shown how honey bees' adventures in finding new homes in the real world develop, as well as whether honey bees can find the best new homes when given different voting methods and with what consensus. As we've seen in previous chapters and research articles like T. D. Seeley [7], and S. Camazine [5], insects in colonies use Majority Voting to make decisions. When things are resolved with Majority Voting in nature, the consensus amount is 90 percent, according to the S. Camazine [5] article. This experiment was carried out in real life in the S. Camazine [5] article, with the bees being marked one by one, the places they went, and the "waggles" they did, being recorded, and the result is obtained in this manner. The behavior of honey bees was simulated and an environment similar to the real world was attempted in the L. Condradt [10] study, which served as the inspiration for this study and thesis. In the L. Condradt [10] study, it was recorded and examined with what percentage they arrived at the best potential hive point using the majority voting method, and then with what consensus they arrived at.

We transformed the real-life behaviours of honey bees ($\Delta_{Indepedence}$, $\Delta_{Interdepence}$, $\Delta_{Chanceoffind}$) into factors in this novel study, which shaped their behaviours and where they go. Honeybees' potential hive has its own randomly assigned quality values, which are designed to be recorded in honeybee memory. These potential hive qualities have provided us with information about where the bees congregate in the simulations, which changes with each simulation. When calculating the results, we use three different voting methods: majority voting, Borda Count, and Liquid Democracy. Each voting method was divided into three categories, and the best potential hive point was determined by examining which consensus rates and at what rate the best potential hive point could be found in each of the three categories.

The reasons for the results will be discussed in the following sections, and we will attempt to provide insight into why things turned out the way they did. Following that, we will compare the rates and results of this novel study to those of similar studies, and finally, we will discuss how far such research can be advanced in the future, as well as the factors that can be changed in this thesis.

6.1 Consensus Rate and Choosing the Best Accommodation

6.1.1 Majority Voting

In the Majority Voting method, our three factors are as follows: Low $\Delta_{Interdepence}$, High $\Delta_{Interdepence}$, and finally $\Delta_{Chanceoffind}$. Figure 12 displays the results of these voting methods. According to these findings, the consensus reached 90% in the Low $\Delta_{Interdepence}$ results, 60% in the High $\Delta_{Interdepence}$ results, and 40% in the Low $\Delta_{ChanceofFind}$ results. They were able to find the best point 50% of the time in the Low $\Delta_{Interdepence}$, 40% of the time in the High $\Delta_{Interdepence}$, and 30% of the time in the Low $\Delta_{Chanceoffind}$ out of ten simulations. In the model we created, the probability of finding the potential hive with the best score was found to be 84 percent. We can see that the Majority Voting method outperforms other voting methods in terms of identifying potential points with a higher consensus and top score.

The reason for this is that honey bees do not have difficulty choosing the best from the moment they arrive at the point with the highest score because their reliability is high and they decide as a majority. When a group of bees claimed to have reached the highest point, the other bees recognized that this point was exceptional in comparison to the others because the bee was telling the truth, and they voted for the advertised location with the highest score. An ant experiment similar to the one we conducted was described in the T. Sasaki article [17], the ants' consensus on the new potential nest was determined, and they also discussed what factors the ants considered, [13] measured and observed to reach consensus rate of 94%. They observed that the ants formed a common idea and chose the new nest site using the majority voting method in the T. Sasaki experiment, and they also took into account the ants' psychological factors.

6.1.2 Borda Count

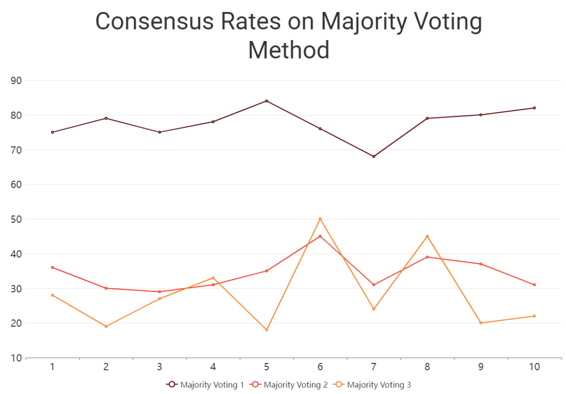

Figure 12: Majority Voting method, consensus rates shown in the line chart.

The Borda Count voting method is one of the more difficult voting methods from which we obtain results. We wanted to see how the results differed when each honey bee or group of honey bees had two or five preferences. Even if honeybees make a preference list, they still vote for the best in the real world; instead, we have honeybees voting as a list. It takes the honey bees' preferences as $A_{\sigma(n)} \succ A_{\sigma(m)} \succ A_{\sigma(l)} \succ A_{\sigma(s)} \succ A_{\sigma(t)}$ and creates a list such as <n, m, l, s, t> once the wandering stage is completed. In the Borda Count voting method, consensus is designed to point to the nest site where the most scores are collected, rather than the part where the majority of the votes are cast.

In our simulations, we looked at three factors: a group of honey bees with two preferences; a group of honey bees with five preferences, and an individual honey bee with two preferences. A total of 15 points is obtained in scenarios[14] with 5 honeybee groups and each honeybee group having two preference lists, with consensus between 5 and 9 points. In the experiments we conducted in this section, they were able to find the point with the highest score in six of them but failed to find it in four, with the majority of points going to the second best point.

In our second ten-bee experiment, we assigned each group of bees a total of five preferences; having five preferences increased the total number of points to distribute and changed the consensus as follows: the potential site, which won from a total of 50 points distributed[15], collected 10 to 18 points and won the election with a consensus of 20 percent to 36 percent.

Each honey bee had a preference list with two options in our previous 10-side experiment. Our

[13] As an example, "Lux Levels"

[14] Each bee group is given three points in total, two of which are given to their first choice and the remaining one to their second choice.

[15] Each bee group is given 10 points in total, four of which are given to their first choice and the remaining points to their remaining choices.

simulations showed a 90% success rate in finding the best potential point, despite the fact that the consensus rates did not change much from the previous experiment. While consent was given, the total number of points was 750, with the winning region receiving between 100 and 120 points, resulting in a consensus rate of 13.5 to 16 percent.

Figure 13 shows the results of the board count method, and we discovered that in scenarios where group votes and preference lists are small, the consensus is higher. Furthermore, when the Borda Count method is used, the hive point with the highest score is chosen less, and the hive point with the second-highest score is chosen more because the bees scoring the highest point will also choose the second-best hive point as their second choice. With the points collected from the first option of the bees who did not go to the hive point with the highest score, the probability of choosing the 2nd hive point with the highest score increased.

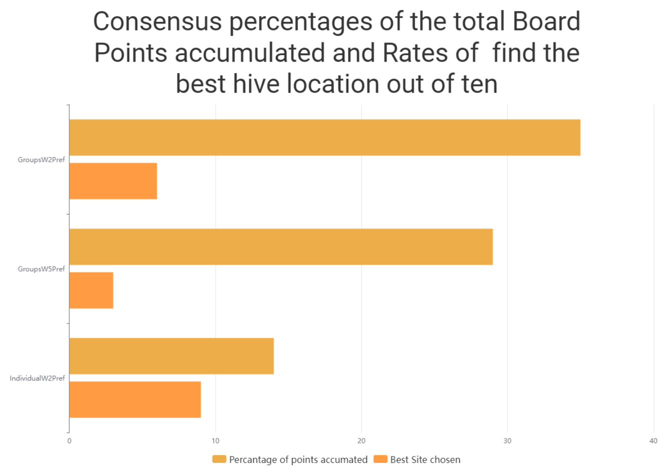

Figure 13: The Figure shows Borda Voting method consensus rates and finding the best hive point out of ten.

One of the important features of the Borda Count voting method is the score shift from the best to the second-best point; this feature was also mentioned in Colman 1980[18], and they concluded an experiment on this feature. A Borda Count method study was conducted in small committees in the Colman 1980 [18] study, and the options were few (7), and it was observed that the votes went to the more ”fair” option where no strong preference existed.

6.1.3 Liquid Democracy

One of the most difficult aspects of this research was the final voting method, Liquid Democracy. While the Liquid Democracy method’s real-world adaptations vary from case to case, the central logic of ”voters may or may not prefer to delegate their voting rights to a trusted proxy” remains constant. With this in mind, we designed our system so that three delegates always promote different hive points as the best hive points in their region and collect votes for them. We created our consensus measurement criteria over $\Delta_{RateofDelegate}$ and examined their consensus at low, medium, and high settings because what makes the Liquid Democracy method unique is the flexible transfer of voting rights. As a result of our experiments, we discovered that increasing the $\Delta_{RateofDelegate}$ factor reduces the consensus rate, and the reason for this is a change in the proportions of the actions that the honey bees will take after each round, for example; If more than 70% of the delegates do not cast their votes, the votes are almost evenly distributed because they constantly transfer their voting rights to each other and the remaining 30% are constantly using their voting rights.

Choosing the best hive point has a different meaning in the Liquid Democracy voting method; already, three of our delegates are falsely advertising that they are the best for their region, providing a reason for the honey bees to grant their voting rights. We looked at the winning probabilities and consensus of the advertised points, not the best quality hive, based on this. Liquid Democracy has a wide range of applications, including decision-making for Ethereum mining (Fan[19]) to the Pirate Party Berlin's adaptation of Liquid Democracy in political aspects[16]. We conducted our Liquid Democracy research in a manner distinct from the areas mentioned, and we observed how honey bees, which act in a more communal manner, influence their decision-making or decisions.

6.2 Future Work

We will discuss where we can move our work, how we can add a different perspective, and finally, can we use such a thing in the real world in the final section of our project. We believe that the more data we have, the better. Our project begins with real-life and progresses to abstract concepts. We believe that every disintegration and voting data will improve the robustness of our research; one of our main curiosities is how important percentages will be and where they will converge in much larger repetitions. In terms of scale, we could say the same thing. We are confident that the greater the number of honey bees in our experiments, will provide much more precise consensus rates. The following components are our one of the main goals in the future of our research: a comparison of our experiments simulation rules with the axioms mentioned in the Handbook of Computational Social Choice [20], specifically for majority voting and board count voting methods.

We have a promising future candidate for our Board Count voting method; we want to compare our results to Mallow's Ranking model[21], but because computational complexity is high and this is not the main topic of our thesis, it is a better fit for the future additions section. Simultaneously, there are cutting-edge studies on probabilistic preference learning in Mallow's ranking, V. Vitelli[22]. At the same time, by using Bayesian Mallow's Ranking, this model can achieve results on consensus. We believe this could be a necessary step for the next stages of our thesis[23].

We believe that by adapting the aggregator axioms and hashes shown in Z. Christoff [9] to the behavior of honey bees, we can provide a sharper result with a more formal proof for the Liquid Democracy adaptation. We believe that honey bees would be unable to behave as freely as Liquid Democracy, but because our work takes place in an abstract world, we can impose any behavior on our honeybees in the best way possible. We tried to implement learning models to our project, inspired by the model we used as an example, Raschkas 2018[24]. We tried to shuffle the data we created with the k-fold technique we used in our model implementation, send it to our model, and use the random forest to test the entire database. However, because there are numerous approaches, it is difficult to predict which model's structure or function will produce better results and produce fewer errors in different voting methods. We abandoned this strategy because any model we developed would not work with any other voting method or produce comparable data. As a continuation of our work and possible future development, a model of these three different voting methods can be created and trained using the results we've generated.

6.2.1 Further Readings

Political Applications in Liquid Democracy, Valsangiacomo 2021[25], Consensus versus majority vote: A Laboratory Experiment, Hare 1980[26]

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