Modeling Collective Behavior in Ants

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To research ants' behavior, we can create and observe a model rather than do field observations. This paper aims to use the ABM model to simulate ants' behavior. In addition, compare with the mathematical model mentioned in [Zachery Shaffer 2013]. This paper discovers that the ABM simulation may be better than the ODE model. Furthermore, this paper does many experiments to discuss what factors may affect the simulation result.

Additional Key Words and Phrases: Ants, ODE model, ABM model, Robot, Earthquake

1 INTRODUCTION

Recently, my home country, Taiwan, is struck by a 7.2-magnitude quake. Several buildings collapsed. I was thinking about how to design a robot to rescue people stuck in collapsed buildings efficiently. This robot must explore the stuck people by itself. It should be able to work in an environment where the road is not flat. If the robot needs help from another robot, it can recruit nearby robots without communicating with the center server for help. The robot's goal is similar to the ants talked about in this paper. The ants are exploring a feeder on the map at the beginning. When it commits to one feeder, it starts transporting food back to the nest. When the ants meet another ant, they share information and recruit them to transport the same food source.

To build an ants-like robot, we must observe and learn from their actions. Rather than doing field observation, we can create a model to simulate their behavior. This idea comes from [Zachery Shaffer 2013]. It delivers a mathematical model to try to simulate it. However, the model performs poorly in some scenarios, so this paper uses Agent-based modeling(ABM) to simulate ants' actions.

The paper [Zachery Shaffer 2013] describes ants' actions with two actions: commit to a feeder and uncommitted. To ease the problem, we assume only two feeders are in this paper. Therefore, there are three states: commit to feeder A, commit to feeder B, and uncommitted. All ants are uncommitted at the beginning. The discovery rate describes the possibility that ants discover a feeder and commit to it. The recruitment rate means the possibility that an ant recruits other ants. After recruitment, the ant commits to the same feeder. The attrition rate represents the possibility that a committed ant transforms into an uncommitted ant. The state diagram is shown in Fig. 1.

This paper aims to create an ABM model and analyze the simulation result. In addition, re-construct the ODE model mentioned in [Zachery Shaffer 2013] and compare this model with my ABM model. This paper discovers that the ABM simulation may be better than the ODE model. Furthermore, this paper does many experiments to discuss what factors may affect the simulation result. Those factors include the discovery rate, attrition rate, recruitment rate, the distance between the nest and feeder, and the size of the map.

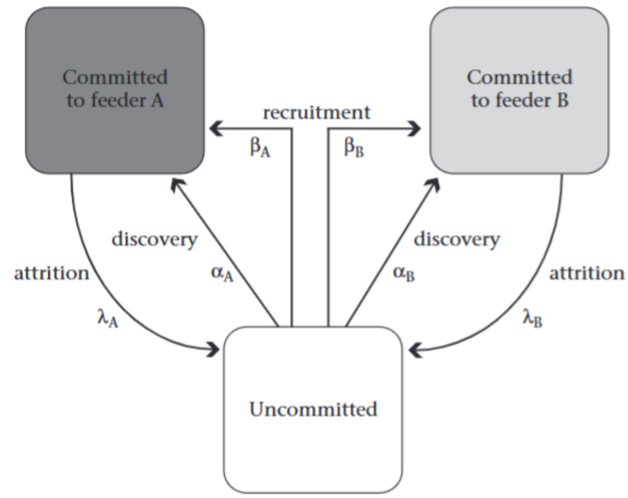


Fig. 1. The state transition diagram for ants. [Zachery Shaffer 2013]

2 ABM MODEL IMPLEMENTATION

The ABM model simulates the possible action that each agent would take in each time step. In this paper's scenario, there are three types of agents: nest, feeder, and ant. In each time step, agent ants could choose several possible actions: do random walks, move to the nest or a feeder, dismiss to commitment to one feeder, or recruit one uncommitted ant. The food unit of a feeder might reduce one if an ant agent removes it. The nest agent does nothing. I implemented the ABM model package, called ABM. I implemented four classes to satisfy this scenario. There are:

- *class Ant*: Handle how an ant moves each time step. If the status of the ant is uncommitted, the ant would choose a feasible direction to move to. When the ant is at a feeder location, there is some possibility that the ant would commit it and reduce one food unit from the feeder. If the ant meets any committed ants while doing random walks, it will commit to that feeder and move to the location of the feeder. If the status of the ant is committed to a feeder, it will move to either the nest or the feeder. There is some possibility that the ant would dismiss to commit to one feeder. At the time, the ant's status turns uncommitted, and it goes back to the nest if it carries any food.
- *class Feeder*: Stored the status of a feeder. If an ant is on it, it would call *Feader.commit/0* to reduce one food unit.
- *class Nature*: This class provides a virtual environment to let agents do their actions. It offers several functions to satisfy agents' need to interact with the environment. For example, they are getting a feasible direction.
- *class Nest*: It stores the information of the nest.

To ease the observation of the experiment result, two classes handle it. They are:

- *class statistic.TimeBase*: After all agents do their actions in a time step, all ants' information will be sent to the class. Then, this class would extract important information and store it in a log file for further use. At the end of the simulation, this class outputs the plot, which is like Fig. 2.

- *class Analyze*: In some experiments, we have to analyze the result using different methods. This class can read the log and do the specified analysis method, like generating a heat map.

3 PART 1

In this scenario, there are three types of agents: nest, feeder, and ant. All the ant agents would initially start at the nest agent (25, 5). Then, ant agents do the random walk until they meet one of two feeder agents, (10, 40) and (40, 40), or are recruited by other committed ant agents. Those committed ant agents could only recruit uncommitted ant agents that surround it. After grabbing a food unit, they will head to the nest agent. However, there is some possibility that the committed ant agent would transform into an uncommitted ant agent. Three parameters control this flow: α, β, and λ. The α represents the feeder agent discovered possibility. The β represents recruitment possibility. Last, the λ presents the possibility of attrition. Each feeder agents have its value. In the feeder A, α is 0.75, β is 0.9, and λ is 0.009. In the feeder B, α is 0.75, β is 0.36, and λ is 0.038. In this section, I will display the result, compare the result with the ODE model mentioned in [Zachery Shaffer 2013], and analyze my ABM model's result.

3.1 Analyze the ABM simulation result

Initially, I put 100 ants in the simulation at the nest. Each ant would randomly walk through the map and follow the abovementioned rule. Fig. 2 shows the result. At the first 350 time steps, no ant commits to a feeder. The reason may be that the ants choose a random direction while doing random walks, making ants walk circularly or head in a direction that is no feeder. The result shows that the number of ants committed to feeder B is more than that of feeder A. This could be the result of recruitment.

3.1.1 The reason ants take 350-time steps to commit to one feeder. I use heat maps to analyze this phenomenon. I create four heat maps to record intervals: 0 100, 100 200, 200 300, and 300 400. Fig. 3 shows the result. The ants expand from the nest to the nearby area after the simulation starts. The area of visited locations increases with the time pass. The figures show the radial expansion from the nest means that the ants keep discovering unvisited locations even though their direction is randomly chosen. Especially it only takes 300-time steps to cover the map, and we can see some cells in the last line colored light blue.

3.1.2 What if we restrict the ants' active area to accelerate the process? In this scenario, the ants can only move in the area where the y-axis should not be smaller than the nest or greater than two feeders, and the x-axis should not be greater than feeder B or smaller than feeder A. Table 1 shows the result. The restriction reduces the 139.92 time steps average. It also accelerates the ant's commitment to any feeder. Overall, the restriction shrinks the map and directs ants to the correct destination, making food depletion more efficient.

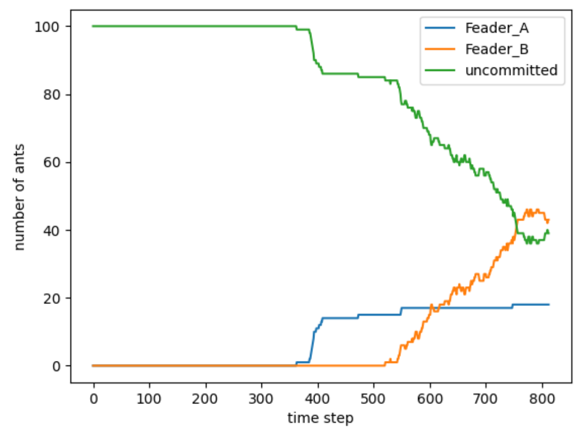
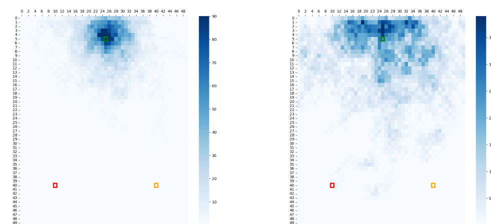
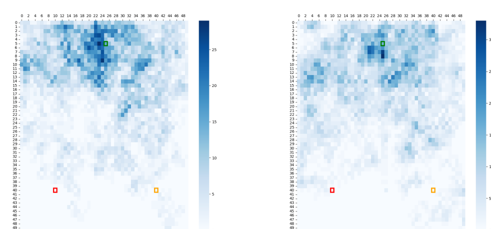


Fig. 2. Shows the result of simulation. The x-axis represents time steps. The y-axis represents the number of ants. The ants start to commit to a feeder at around time step 350. One of the feeders is depleted at the 810-time step. The number of ants committed to feeder A is more than that of feeder B at the beginning. However, we can see that feeder A loses domination at the end, which means some ants change their mind.



(a) Between time step 0 to 100 (b) Between time step 100 to 200



(c) Between time step 200 to 300 (d) Between time step 300 to 400

Fig. 3. The heat maps of four intervals. The green square represents the location of the nest. The red square represents the location of the feeder A. The orange square represents the location of the feeder B.

3.1.3 How the feeder B surpasses feeder A?. There are two ways to turn the committed ants from feeder A to feeder B. One is recruitment, and the other one is attrition. However, it is problematic since the recruitment rate of feeder B, 0.36, is less than feeder A, 0.9. In addition, the attrition rate of feeder A is only 0.009, which is

Table 1. This table shows that the restriction helps reduce food depletion time. Each condition is tested in 50 rounds and at most 1800 time steps in each round.

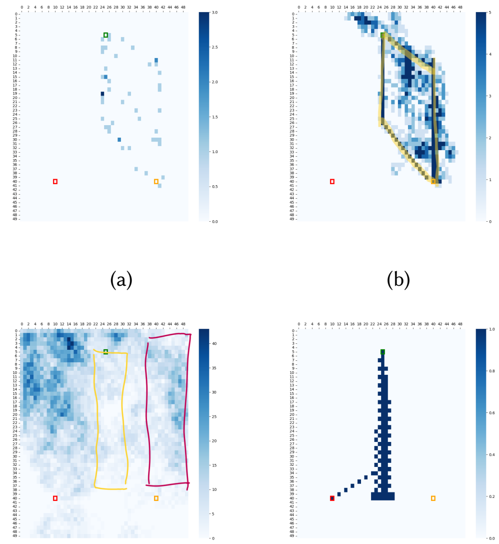
	No restriction	With restriction
Average	795.72	655.8
Maximum	1800	1800
Minimum	328	282
The first ant commit at	428	208

Table 2. This table shows the statistics of the method ants use to commit to a feeder between 500 and 800 time steps during feeder B bypassing feeder A. From these statistics, the number of ants recruited by feeder B is significantly more than feeder A, which is 50 compared to 4. In addition to feeder B, one ant recruited 50 ants, which shows the importance of recruitment in this process.

	Feeder A	Feeder B
By visiting	0	1
By recruitment	4	50

small compared to feeder B, 0.038. Therefore, turning the committed ants to feeder B is hard; the ants committed to feeder B is easy to become uncommitted. As a result, there is only one way that feeder B surpasses feeder A: the uncommitted ants, who all commit to feeder B without being recruited by feeder A. However, the amazing thing happened. Table 2 shows most of the ants committed to feeder B are recruited. In addition, an ant committed to feeder B by visiting could change the result by recruiting, showing that recruitment plays a huge role in this process.

My next question is why feeder A, which has a higher recruitment rate, can not do this. First, let's see where the recruitment of feeder B happened. Fig. 4(a) shows where ants are recruited by feeder B. If we compare the path that committed ants move between nest and feeder B, Fig. 4(b), it is easy to see that those committed ants recruit uncommitted ants on their path. The red block becomes the important source for feeder B's recruitment When observing the distribution of uncommitted ants, shown in Fig. 4(c). This would be proved later. Therefore, the important reason that feeder B could recruit more ants is that there are many ants near the path between the nest and feeder B. Let's see what happened to feeder A. The path where ants committed to feeder A is in the middle of the map, shown in Fig. 4(d). The primary recruitment source is the yellow block in Fig. 4(c). We can see that it shares the recruitment area with feeder B. This should benefit feeder A since it has a higher recruitment rate and low attribution rate. However, feeder B has another primary recruitment source to add more uncommitted ants to join feeder B. When feeder A's ants are dismissed, they have more chance to be recruited by feeder B since the number of ants committed to feeder B is more significant than feeder A. As a result, this is why I think feeder B could bypass feeder A.



(a) (b) (c) (d)

Fig. 4. (a) Shows where recruitment of feeder B happened. (b) Shows how ants committed to feeder B move between nest and feeder B. The yellow line is the main outline of the path. (c) Shows the distribution of uncommitted ants. The red block outlines an area that is an important recruitment source for feeder B. The yellow block outlines an area that is the only recruitment source for feeder A. (d) Shows the path where ants committed to feeder A move between nest and feeder B.

3.2 Re-construct ODE model

The paper [Zachery Shaffer 2013] introduces a mathematics model to describe this phenomenon. Equation 1 and 2 are models for two feeders. Fig. 5 is the ODE model results with the same parameters used in the ABM model. In the ODE model, it becomes flat very soon, taking only ten steps. It predicts that feeder A would get more ants than feeder B, which is different from the result of the ABM model. This result is more intuitive if we only see the parameter since, as I said in the previous sections, feeder A should get more ants due to its high recruitment and low attrition rates. However, we must consider space in reality, making ABM's result more reasonable.

$$\frac{\partial X_A}{\partial t} = \alpha(N - X_A - X_B) + \beta_A X_A(N - X_A - X_B) - \lambda_A(N - X_A - X_B) \quad (1)$$

$$\frac{\partial X_B}{\partial t} = \alpha(N - X_A - X_B) + \beta_B X_B(N - X_A - X_B) - \lambda_B(N - X_A - X_B) \quad (2)$$

4 PART 2

In part 2, we are going to discuss the effect of parameters. There are several experiments conducted to disclose it. The first is to answer how the distance to the nest would change the game. The second displays how discovery, recruitment, and attrition rates overcome distance attraction. The third one reveals whether the number of

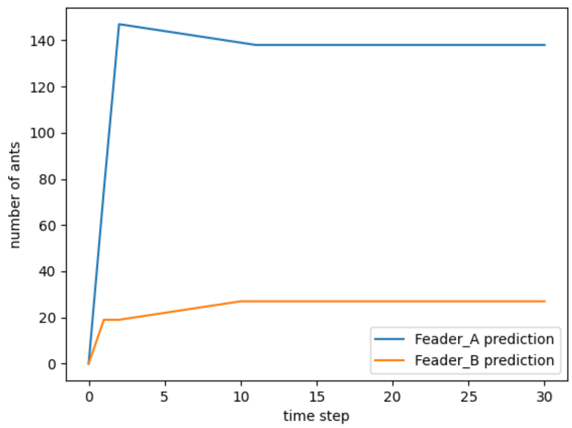


Fig. 5. The result of the ODE model mentioned in [$Zachery\ Shaffer$ 2013]. Parameters mentioned in the ABM model apply to the ODE model.

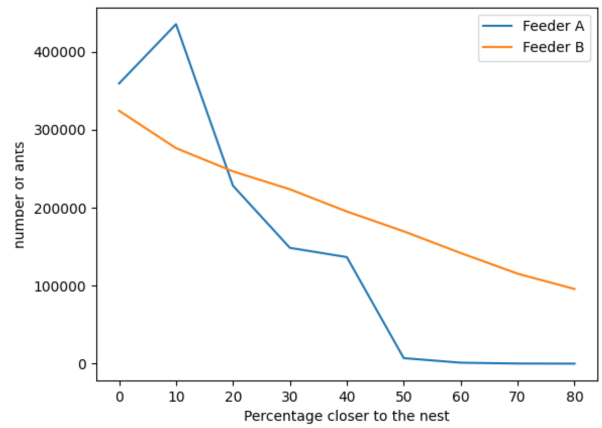


Fig. 6. Shows how many distance percentages should be reduced between feeder B and the nest. The 20% shortage of the distance makes the depletion competition of two feeders a fair game. An above 20% shortage of distance makes feeder B dominate this competition.

Table 3. This table shows the number of ants committed to each feeder. It is the result of three rounds fifty times each. From the result, feeder A got a significant number of ants than feeder B.

	First round	Second round	Third round
Feeder A	613327	494633	609002
Feeder B	299946	295300	313946

Table 4. The source of ants that commit to feeder B. Most of the ants commit to feeder B by recruitment.

	Feeder B
By visiting	2
By recruitment	48

feeders' food units determines the speed of depletion. The last one discusses what would happen if we added more feeders to the map.

4.1 Define the weaker feeder

In the previous section, the feeder A's parameters, discovery, recruitment, and attrition, are 0.75, 0.9, and 0.009, respectively. The feeder B's parameters are 0.75, 0.36, and 0.038, respectively. We can see that feeder B is the weaker feeder since its recruitment rate is lower and the attrition is higher than feeder A. However, the result in section one does not agree with it. It shows that even though those values of parameters make feeder B a weaker feeder, the factor of space and uncommitted ants distribution may play a role in the result. Therefore, I counted the number of ants committed to each feeder in three rounds fifty times each. Table 3 shows the result. We can see that feeder A dominates feeder B, so feeder B is the weaker feeder.

4.2 Experiment: How does the distance between the nest and feeder affect the result?

Feeder B is an acceptable candidate for this experiment since it is the weakest feeder according to the experiment result of the previous subsection. In this experiment, the distance between feeder B and the nest would be reduced by 10% in each round. Besides, the number of ants committed to feeder B or feeder A is the total of the 50 times simulation run. The result is shown in Fig. 6. Feeder B gets the short-distance benefit after 20% shortage. In addition, nearly no ants are committed to feeder A after a 50% shortage of feeder B's distance.

4.3 Experiment: How three parameters overcome the benefit of distance shortage

In the last subsection, we can see that feeder B only needs to be put 30% closer to the nest to attract more ants. Therefore, this subsection focuses on changing the parameters of feeder A. To determine which parameter to tune, we first see how those ants commit to feeder B. Table 4 shows that 98% of committed ants are recruited to feeder B, so reducing the recruitment rate of feeder B may increase the number of ants commit to feeder A. Not only the recruitment rate of feeder B but also reducing the discovery rate of feeder B may achieve the goal since it will stimulate ants to discover more areas rather than commit to feeder B. The following two subsections introduce the result. However, increasing the attrition rate does not help since turning committed ants into uncommitted ants does not prevent them from committing to feeder B again, Fig. 7.

4.3.1 Reduce the recruitment rate of feeder B. In this experiment, the recruitment rate of feeder B decreases 70% in each round. Fig. 8 shows that they are tied when the recruitment rate of feeder B is 49% of the original rate. When the recruitment rate of feeder B is 34.3%

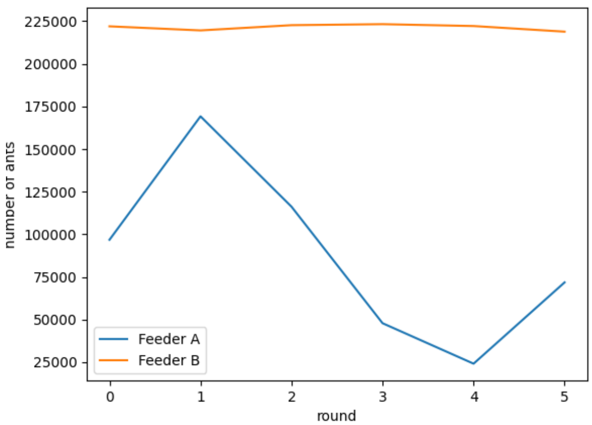


Fig. 7. Shows the change in the number of ants committed to one of the feeders. In each round, the attrition rate of feeder A is 70% less than in the last round. The result of each round is the sum of 50 runs of simulation. No matter how low the attrition rate feeder A has, it still cannot win feeder B.

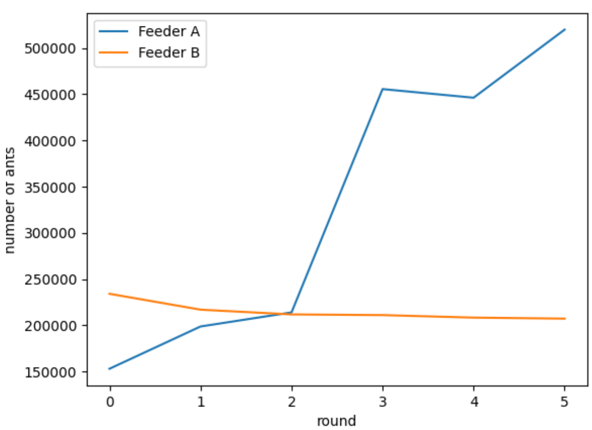


Fig. 8. Shows the change in the number of ants committed to one of the feeders. In each round, the recruitment rate of feeder B is 70% less than in the last round. The result of each round is the sum of 50 runs of simulation. Feeder A dominates this competition when the recruitment rate of feeder B is 34.3% less than the original rate.

of the original rate, which is 0.12348, the number of ants committed to feeder A increases.

4.3.2 Reduce the discovery rate of feeder B. Not only does reducing the recruitment rate of feeder B make this change, but also reducing the discovery rate of feeder B could achieve this goal. Fig. 9 displays that the discovery rate of feeder B is 34.3%, which is 0.25725, less than the origin would lead feeder A to be attracted.

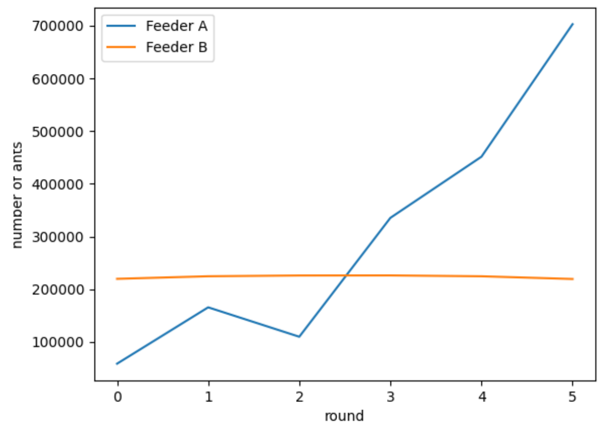


Fig. 9. Shows the change in the number of ants committed to one of the feeders. In each round, the discovery rate of feeder B is 70% less than in the last round. The result of each round is the sum of 50 runs of simulation. Feeder A dominates this competition when the recruitment rate of feeder B is 34.3% less than the original rate.

Table 5. Shows how many times a feeder is depleted first. Each row is tested in 50 rounds.

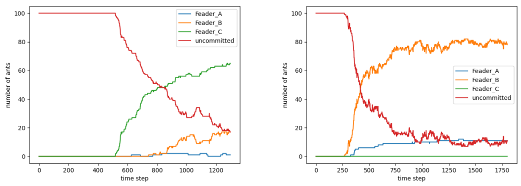
Food unit of feeder A	Feeder A	Feeder B
100	0	25
50	0	21
25	0	24
5	12	22

4.4 Experiment: Does the amount of food unit affect the speed of depletion?

Initially, each feeder has 100 units of food. If we reduce the food for a feeder, the feeder may be depleted sooner. From the section *Experiment: How does the distance between the nest and feeder affect the result?*, we know that 30% of distance shortage leads feeder B to become attractive, so if feeder A is the first depleted, the food unit could overcome the benefit of short distance. Table 5shows that only the food unit of feeder A is less than 5, feeder A would deplete faster than the short distance. It shows that the distance still matters in this model.

4.5 Experiment: What happens if we add one more feeder?

The extra feeder, feeder C, would be added in the middle of the other two feeders. The food unit of feeder C is the same, 100. If feeder C is a strong feeder, which means the value of parameters is the same as feeder A, feeder C will dominate three feeders, Fig. 10(a). The reason is that the path from the nest to feeder B overlaps the path from the nest to feeder C. Since feeder B has an extra source of uncommitted ants, as I mentioned in the section *part 1*, plus it has a higher attrition rate, plus feeder C has a higher recruitment rate, more and more ants would commit to feeder C. On the contrary, if



(a) (b)

Fig. 10. Shows the result of simulation. (a) Add one strong feeder between feeder A and B. (b) Add one weak feeder between feeder A and B.

feeder C is a weak feeder, which means the value of parameters is the same as feeder B, feeder B will dominate three feeders, Fig. 10(b). This is because it is hard for feeder C to steal ants from feeder B. Therefore, the result is the same as the section *part 1*.

REFERENCES

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