Modeling and Optimization of the First-mile Intelligent Scheduling Problem in the Agricultural Product Supply Chain

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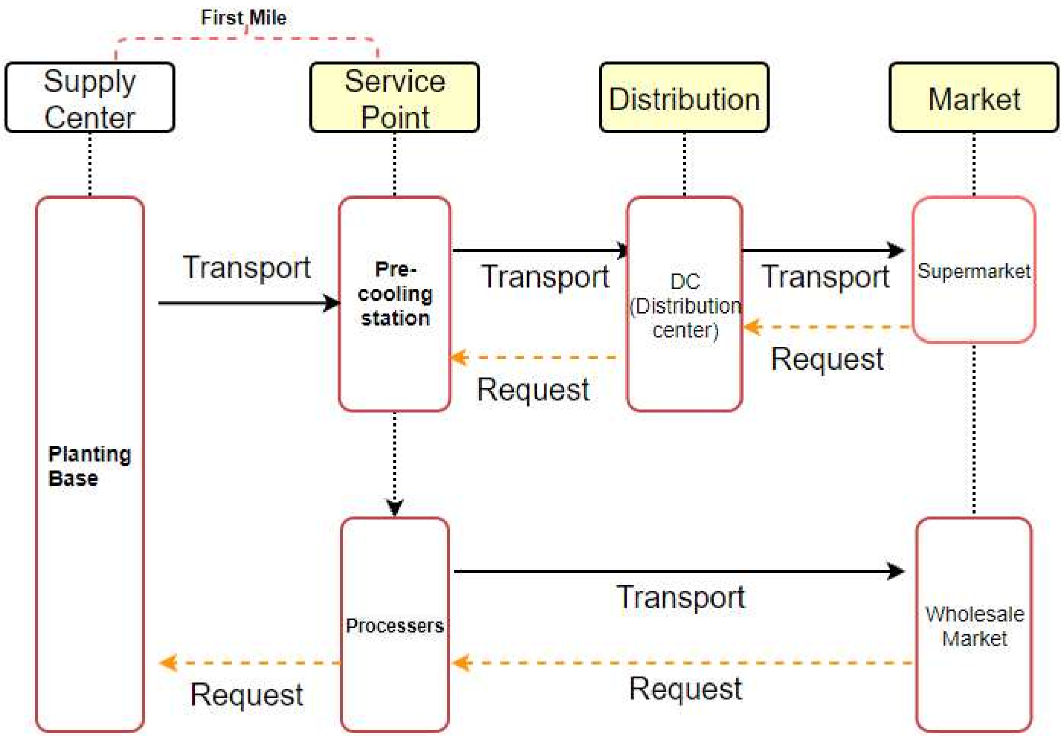
Abstract

In the current agricultural logistics supply chain, the first mile is largely neglected. The traditional supply chain pays more attention to the last mile of downstream clients. However, due to the shortcomings of China's cold chain logistics, many agricultural products have spoiled and rotted before they reach the customers. According to statistics, the annual post-production loss of fruits and vegetables in China is 15%-25%, and the yearly loss is nearly 200 million tons. The reasons for these problems are the shortage of equipment and the lack of information sharing and transparency in the sale of agricultural products, and the mismatch between production and marketing. In response to these issues, this paper puts forward the use of blockchain in the first mile of the agricultural supply chain to establish an information storage platform to achieve real-time intelligent scheduling. The model includes allocating available resources to the first mile of tasks and optimization of construction and operation cost while considering constraints such as capacity and time window. Describes a heuristic algorithm based on black hole optimization, and the algorithm is validated using different benchmark functions.

I. Introduction

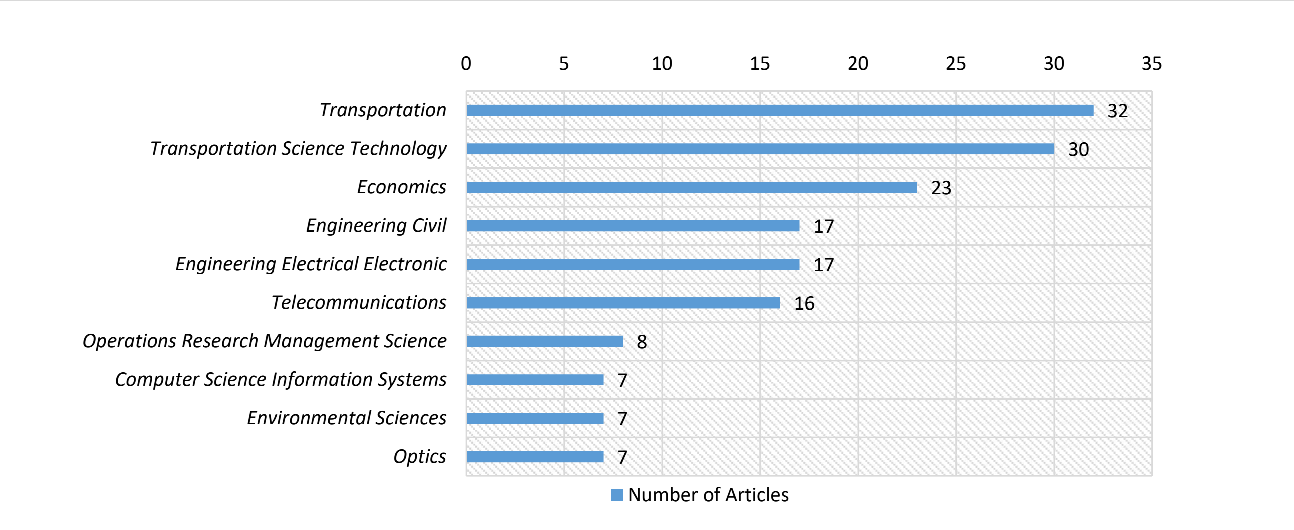
- To improve the quality of the supply chain, many scholars have conducted a lot of research on last-mile issues: such as using last-mile delivery to increase consumer satisfaction, using drones for last-mile delivery to improve timeliness, and using vehicle path optimization to reduce the last mile produce spoilage, and so on. While most research focuses on the last-mile, and for agricultural products, the first-mile is also crucial.
- According to the statistics of the *Planning and Design Institute of the Ministry of Agriculture and Rural Affairs*, the post-production loss rate of fruits, vegetables, and potatoes in China is as high as 15% to 25%, and nearly 200 million tons of agricultural products are lost every year.
- This study tries to find the most suitable location for a pre-cooling station by constructing a first-mile optimal scheduling model to achieve transportation and construction cost minimization and ensure subsequent supply chain development.

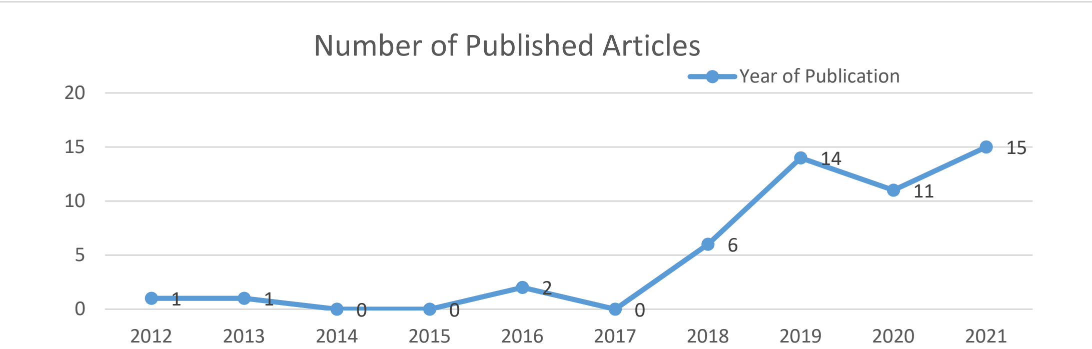
I. Introduction



The supply center is the starting point of the first mile and the first-tier node of cold chain logistics, mainly including farmers and planting bases, etc., which are responsible for producing and providing agricultural products.
Since agricultural products need to be pre-cooled as soon as possible after being picked and lowered to the lowest temperature to ensure their quality, the supply center transports the agricultural products to the service point for preliminary pre-cooling and processing.
The service point should also have the functions of grading and packaging so that the agricultural products can be directly transported to the next level of the supply chain, such as the distribution center or wholesale markets.

II. Literature review

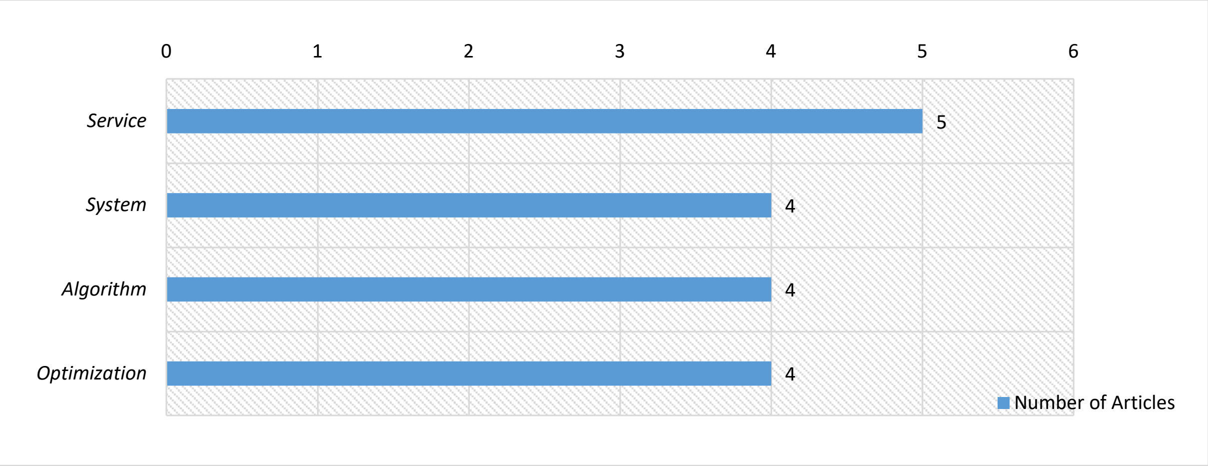




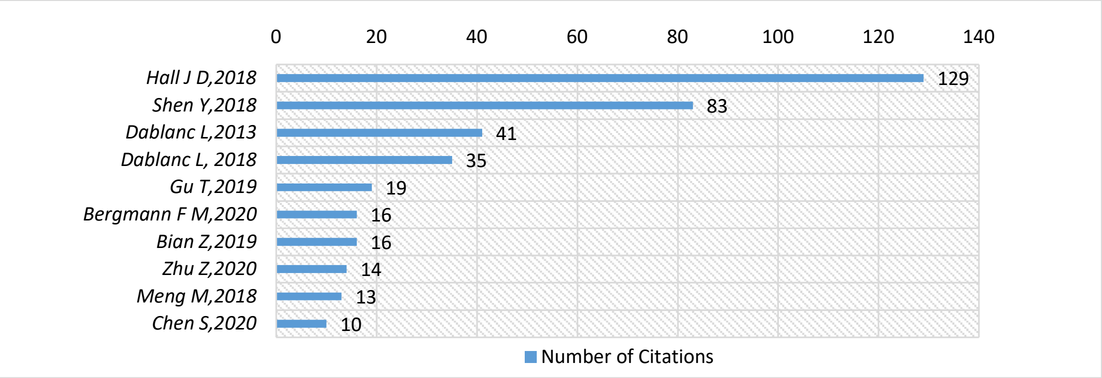
Search TS=("first mile" OR "first-mile") to get 100 results, classify the searched articles according to topics, and show the classification of these 100 articles considering ten subject areas. This classification shows most transportation, transportation science and technology, and economics and defines the importance of calculation methods related to decision science. The first article in this field was published in 2000, "In the First Mile" ,about the importance of first-mile service.

Filtering the categorized list, there are 50 papers in fields such as transportation and economics. As seen by the time of publication, the first article was published in 2012, describing the first-mile on-highway operations. The increase in the number of published papers in recent years, as shown in the figure, also indicates the importance of research in this field.

II. Literature review



The statistical distribution of the most commonly used keywords is shown in the figure. The first-mile solution is designed based on service and optimization.



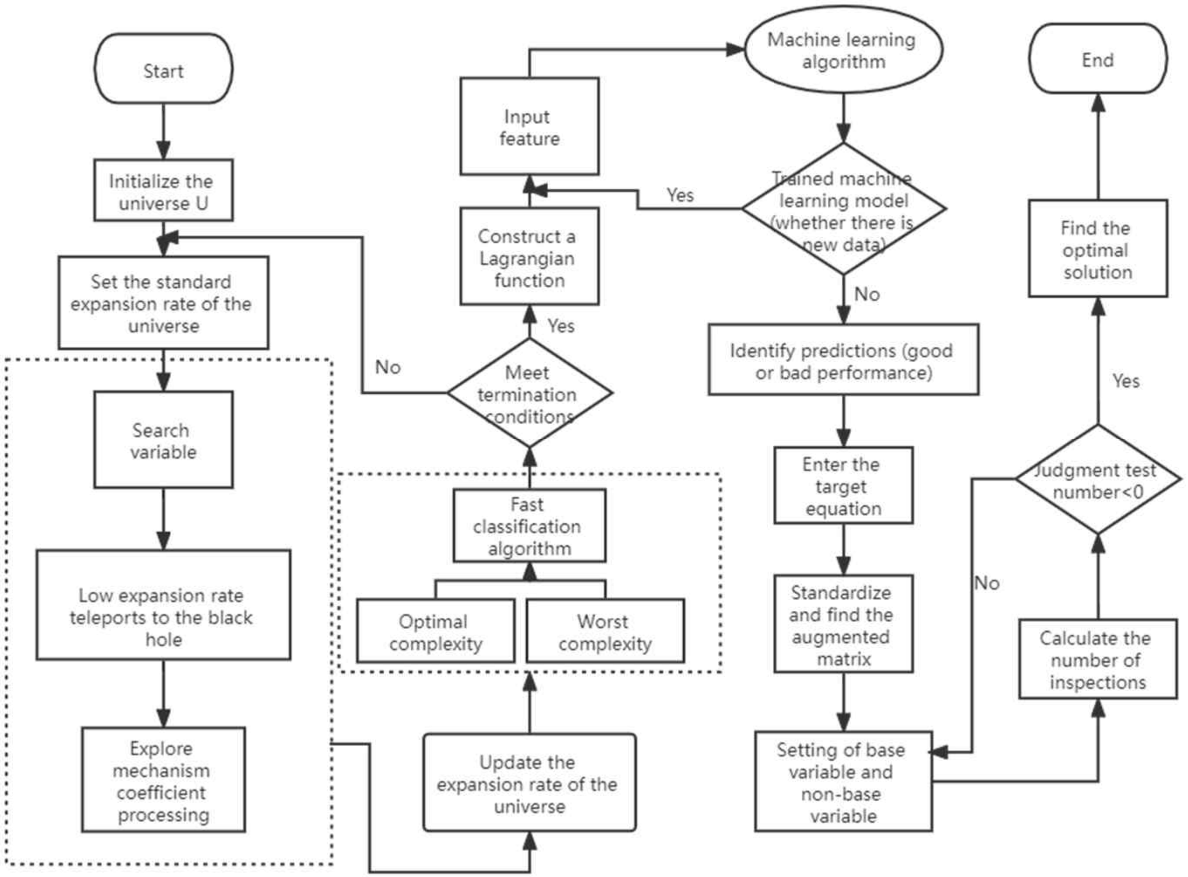
The most common way to assess an article from a scientific impact perspective is to look at its citations, as the figure shows the top 10 most cited articles and their citation counts[6]-[15].

III. Model Framework

Basic assumptions: To ensure the scientificity and feasibility of the model establishment, the following relevant basic assumptions are proposed:

- **Assumption 1**: There is no network construction near the agricultural products growing base for the time being.
- **Assumption 2**: The off-peak and peak seasons of agricultural products are not considered, and the supply is known.
- **Assumption 3**: The distance between the planting base and the service point is the straight-line distance between the two points.
- **Assumption 4**: The vehicle runs at a constant speed, and there are no other problems.
- **Assumption 5**:The temperature changes during transportation and the impact on different agricultural products are not considered.

III. Model Framework



Through the analysis of MIP, SVM, and BHO algorithm, this study proposes using the BHO algorithm to optimize the SVM parameters and then the optimization of the control parameters in the SVM so that MIP can find the most relevant results more quickly.

The specific steps of algorithm implementation are as follows.

Step 1: Collect the required data and initialize the relevant parameters.

Step 2: Set the optimization objective function and constraint range.

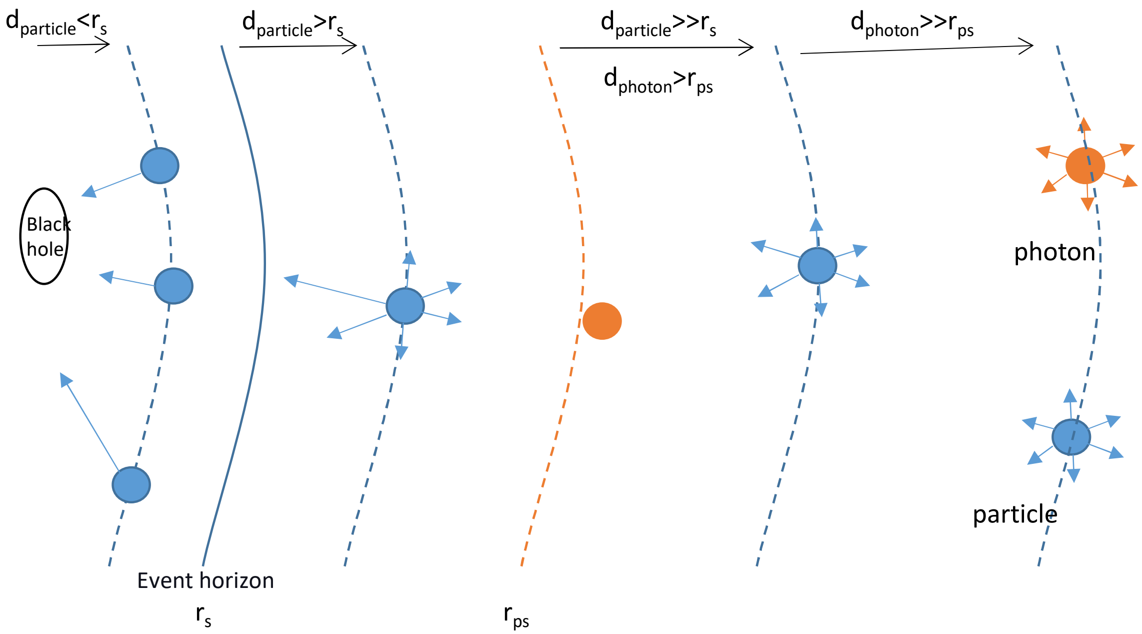
Step 3: Invoke the BH algorithm to search for the function corresponding to the optimal value of the fitness function for SVM training.

Step 4: Test the training model, deriving the test results, and putting them into the planning solver.

Step 5: Get the best position result.

III. Model Framework

Black Hole Optimization Algorithm (BHO)



The moving behavior of different particles depends on the distance between the particle, the event horizon and the photon sphere.

The black hole algorithm is an algorithm concept in the Multi-Verse Optimizer Algorithm (MVO), which simulates the black hole phenomenon in the universe. Under the strong attraction of the black hole, the stars around the black hole accelerate to move to the black hole, thereby improving the convergence speed of the algorithm. In a black hole, the gravitational(중력) force is enormous. Not only can it capture particles, planets, and stars, but also light or radiation. But the attraction of a black hole is that the closer it is to the black hole, the greater the gravitational force. This boundary is the event horizon, and its radius is the Schwarzschild radius. The calculation formula is as follows:

$$r_s = \frac{2Gm}{c^2}$$

Gravitational constant

Mass of the celestial body

Speed of light

Schwarzschild radius

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III. Model Framework

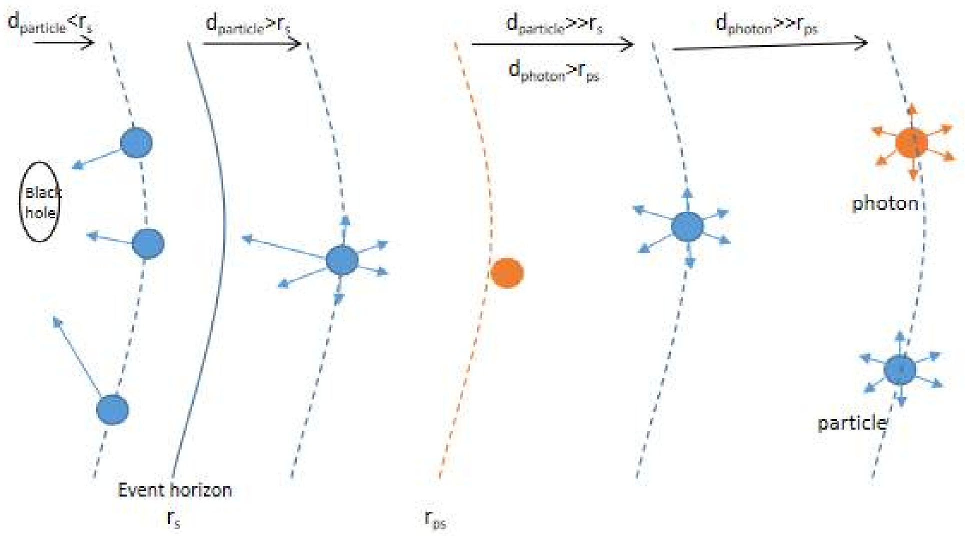
Black Hole Optimization Algorithm (BHO)

In the iterative process, the stars that reach the event horizon will be absorbed. A new star will be generated in the search space, representing a new candidate solution to the optimization problem, with the total number of stars remaining unchanged. The radius of the event horizon (Schwarzschild radius) is calculated as follows:

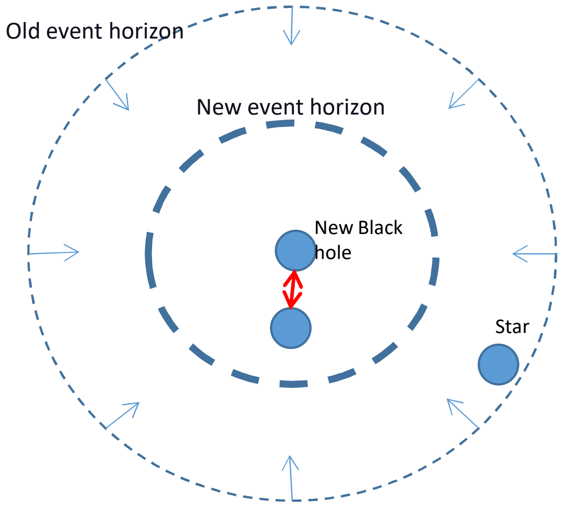
The solution in the event horizon is regarded as the region where the optimal solution is located, and the black hole itself is regarded as the optimal global solution. All other stars in the search domain will gravitate and from which they cannot esca and the equation for a star to be attracted by the black hole a move closer to the black hole is:

$$x_i(t+1) = x_i(t) + rand \times (x_{BH} - x_i(t)), i = 1,2,\ldots,N$$

Where: $x_i(t)$ and $x_i(t+1)$ represent the position of the i_{th} star at t and t+1 respectively; rand denotes the random number between [0, 1]; x_{BH} is the black hole the search space; N is the number of stars.



III. Model Framework



In the process of being attracted to the black hole, if the fitness function of a star i is better than the fitness function of the black hole f_{BH}, then the position of the black hole is not optimal, and the black hole and the star need to swap their positions. Then the algorithm will continue to run with the newly created black hole as the center, and the other stars will re-flow to the new black hole position and be absorbed by it through the position replacement formula.

III. Model Framework

Support Vector Machine (SVM)

The support vector machine is a linear classifier that can classify labeled data, and the classification line in high dimensions is called a hyperplane.

- Mainly for classification and prediction
- Classify labeled data, and its high-dimensional classification line is called a hyperplane
    - If in a high-dimensional classifier, the distance from a point to a line can be understood as the distance from a point to a hyperplane, according to the formula for the distance from a point to a surface:

$$d = \frac{|Ax_0 + By_0 + Cz_0 + D|}{\sqrt{A^2 + B^2 + C^2}}$$

- Distance from the point to the line is as large as possible, and the larger it is, the higher the confidence of the classification

In the formula, $Ax_0 + By_0 + Cz_0 + D$ =0, the coordinates of point P are (x_0, y_0, z_0), and d is the distance from point P to the plane.

The distance formula can be expressed in the form of a vector as:

$$\gamma^{(i)} = \frac{\omega^T x^{(i)} + b}{||\omega||} = (\frac{\omega}{||\omega||})^T x^{(i)} + \frac{b}{||\omega||}$$

Distance maximization

$$max_{\gamma,\omega,b}\gamma$$

$$\text{s.t.} \quad y^{(i)}(\omega^T x^{(i)} + b) \geq \gamma, i = 1, \ldots, m$$

$$||\omega|| = 1$$

Rewritten

$$min_{\gamma,\omega,b}\frac{1}{2}||\omega||^2$$

$$\text{s.t.} \quad y^{(i)}(\omega^T x^{(i)} + b) \geq 1, i = 1, \ldots, m$$

III. Model Framework

Mixed Interger Programming (MIP)

Symbol	Description
n	Number of production areas
m	Number of alternative stations
d_{ij}	Distance from production area i to alternative station j (unit km)
$x_{ij} = 1$	Path from production area i to alternative station j is selected
$x_{ij} = 0$	Path from production area i to alternative station j has not been determined
a_{ij}	Delivery volume of agricultural products delivered from origin i to alternative station j (unit ton)
d_{max}	Prigin i to alternative station j's maximum distribution distance
c_{ij}	Cost per unit weight of agricultural products transported per unit distance from origin i to alternative station j (unit: yuan/ton kilometer)
U_i	Average daily supply quantity of the ith origin (unit ton)
V_j	Average daily purchase quantity of the jth alternative station (unit ton)
$\bar{c}$	The cost of the service point
$\min\|\|\bar{x}\|\|_o$	Make the construction of as few service points as possible
P	The transportation cost matrix

When performing the service point layout, first determine the selection matrix X and the distribution matrix A. When the jth column of X is equal to 1, it means that the jth candidate network point is selected; The distribution matrix A represents the volume of product distribution from produce growing base i to alternative station j for picking.
So the matrix X can be expressed as $X = (x_1, x_2, \dots, x_n)^T$
To save costs more intuitively, it is necessary to make the construction of as few service points as possible, which can express as . $\min||\bar{x}||_o$
Now suppose that the cost of the service point is C, and the number of alternative station to be constructed is the least, then : $\min\bar{c}||\bar{x}||_o$
The transportation cost matrix can be expressed as , $P = C \times A \times D \times X$
the minimum transportation cost at this time can be expressed as: $\min \sum_i \sum_j p_{ij}$

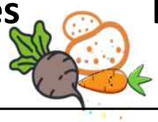
$$\min \underbrace{\bar{c}}_{\text{the cost of the pre-cooling point}} ||\bar{x}||_o + \min \underbrace{\sum_i \sum_j p_{ij}}_{\text{transportation cost}}$$

$$s.t. \quad d_{ij}x_{ij} \le d_{max}, i = 1,2,\dots,n; j = 1,2,\dots,m$$

$$\sum_{i=1}^{m} a_{ij}x_{ij} = U_i, i = 1,2,\dots,n$$

$$\sum_{i=1}^{m} a_{ij}x_{ij} \le V_j, j = 1,2,\dots,m$$

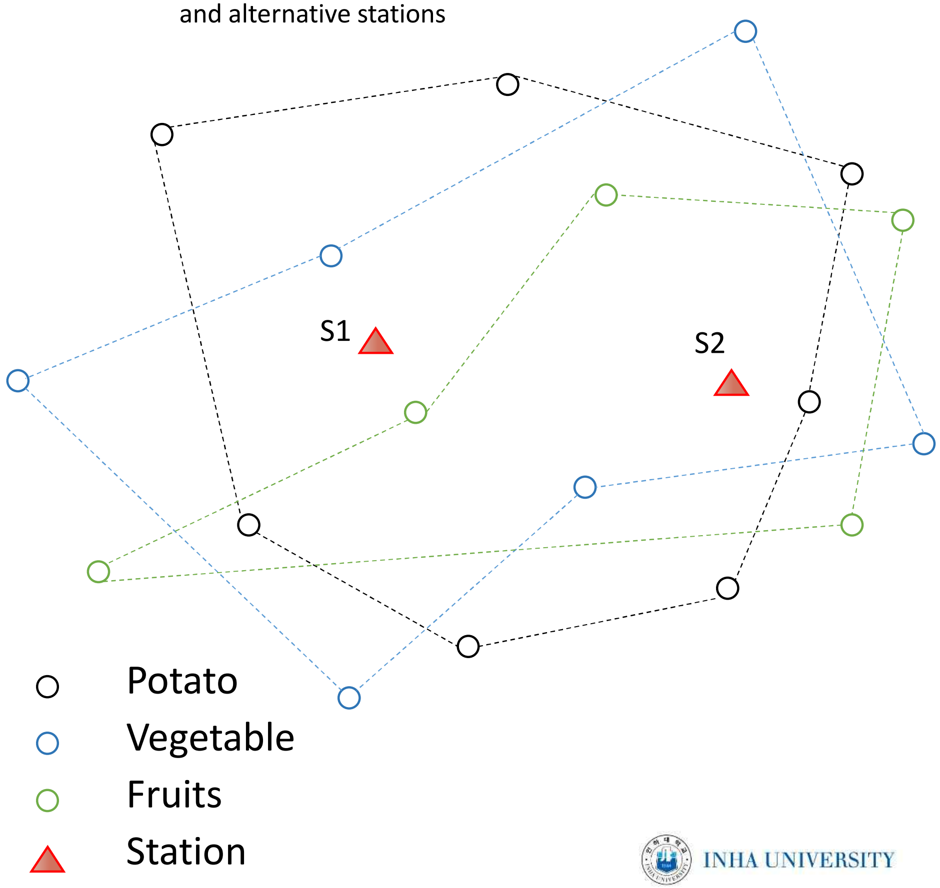
IV. Scenario analysis of agricultural products intelligent dispatching

Item	Leaves (vegetable) 	Rhizomes (potato) 	Fruits 
Length	≤ 30	≤ 20	$\leq 30cm$ (eggplant/corn)
Width	≤ 10	≤ 7.5 perimeter≤ 24	≤ 8 perimeter$\leq 25cm$
High	≤ 10	≤ 8	$\leq 10cm$
Weight	≤ 800 (cabbage)	≤ 1000 (radish)	$\leq 300g$ (tomato)

Label features of various types of agricultural products

*Reference agricultural product quality inspection data

Simple demonstration of agricultural produce planting areas and alternative stations



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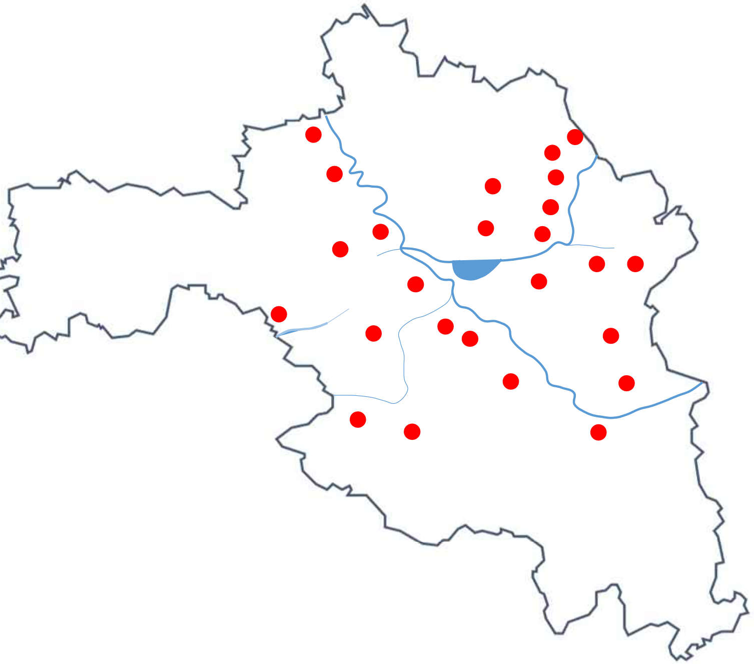
IV. Scenario analysis of agricultural products intelligent dispatching



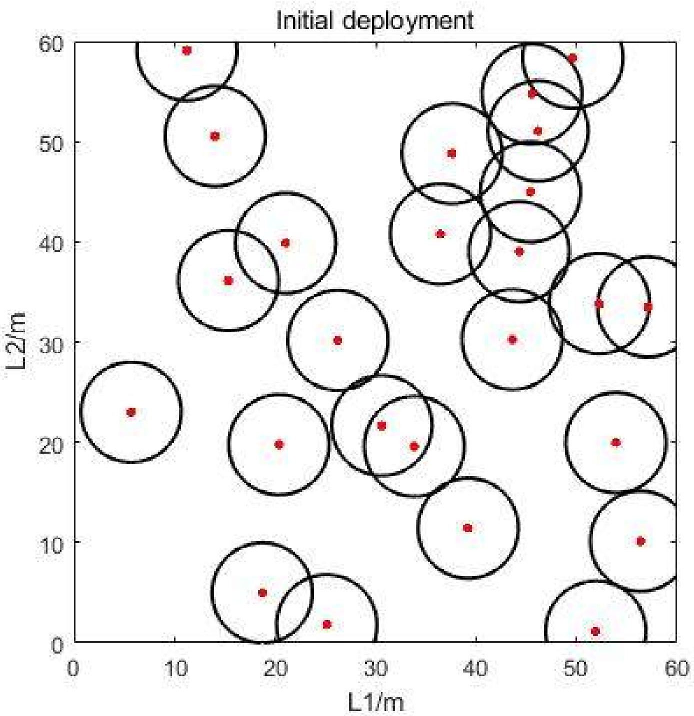
Initial position：

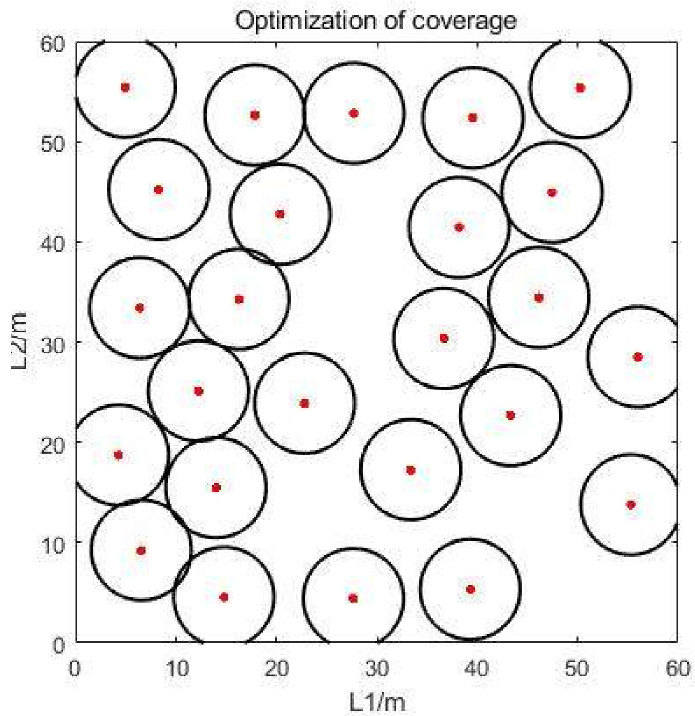
36.4758	40.7983
37.6451	48.8051
33.8707	19.5951
49.6844	58.3523
45.4487	44.9718
11.1793	59.0988
30.6341	21.6788
25.1357	1.7975
15.3256	36.1323
21.0343	39.8743
53.982	19.9635
44.3269	39.0184
51.965	1.1589
56.4381	10.1366
46.2161	51.0625
18.7112	4.9908
20.3733	19.7627
57.1561	33.5048
5.6284	23.0205
39.2398	11.427
45.6027	54.742
26.256	30.185
43.6443	30.2612
13.9991	50.55
52.329	33.8382

As the research scene, City Z has an area of 960 square kilometers. It is known that City Z contains 9 towns, but among these 9 towns, only the town by the river has crop output, and the distance between these towns is not large. *(All these towns can be used as agricultural product planting bases and alternative pre-cooling stations.)*

The number of production sites n=25, numbered 1 to 25 sequentially, and the number of alternative pre-cooling stations is m=25, the numbers are A to Y. To ensure the quality of agricultural products, it is best to send them to the pre-cooling station for pretreatment within 30 minutes after picking. Given that the average vehicle transportation speed is 60km/h, the maximum allowable transport distance for agricultural products to the pre-cooling station is 30km, ie. $d_{max} = 30$

IV. Scenario analysis of agricultural products intelligent dispatching





Optimal position：

6.5039	9.2454
12.2059	25.1085
56.0763	28.5223
46.1775	34.449
38.2246	41.4443
27.7117	52.8305
27.6732	4.4122
20.3657	42.7504
14.7524	4.5545
39.3308	5.3372
4.8913	55.4275
36.6941	30.3595
47.4906	44.929
17.8309	52.6425
33.4026	17.2656
43.3719	22.683
39.6071	52.3648
4.2303	18.7315
8.2466	45.2226
6.3492	33.41
16.236	34.2764
55.3663	13.7941
50.3079	55.3727
22.8107	23.9028
13.9595	15.469

V. Result

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	43.5	28.9	23.1	11.6	1.9	14.9	37.4	16.2	42.3	35.6	34.8	10.4	11.8	22.1	23.7	19.4	12.0	39.1	28.6	31.0	21.3	33.0	20.1	21.7	33.9
2	50.4	34.8	27.4	16.7	7.4	10.7	45.5	18.3	49.8	43.5	33.4	18.5	10.6	20.2	31.8	26.7	4.1	45.0	29.6	34.9	25.9	39.2	14.3	29.0	40.9
3	29.3	22.4	23.9	19.3	22.3	33.8	16.4	26.8	24.3	15.3	46.1	11.1	28.8	36.7	2.4	10.0	33.3	29.7	36.2	30.8	22.9	22.3	39.4	11.9	20.3
4	65.4	50.1	30.5	24.2	20.4	22.7	58.3	33.2	64.1	54.0	44.9	30.9	13.6	32.4	44.2	36.2	11.7	60.3	43.5	50.0	41.2	44.9	3.0	43.7	55.8
5	52.8	38.7	19.6	10.5	8.0	19.4	44.3	25.2	50.8	40.1	41.9	17.0	2.0	28.7	30.2	22.4	9.4	48.9	37.2	40.8	31.1	32.7	11.5	30.9	43.2
6	50.1	34.0	54.3	42.8	32.3	17.7	57.1	18.8	54.7	60.7	7.3	38.4	39.0	9.3	47.4	48.6	29.2	41.0	14.2	26.1	25.3	63.3	39.3	37.1	43.7
7	27.1	18.7	26.3	20.1	21.2	31.3	17.5	23.4	23.4	18.5	42.4	10.6	28.7	33.5	5.2	12.8	32.0	26.6	32.5	27.0	19.1	26.0	39.0	8.1	17.8
8	20.1	26.7	40.9	38.8	41.8	51.1	3.6	41.2	10.7	14.6	57.3	30.8	48.6	51.4	17.5	27.7	52.6	26.9	46.6	36.8	33.7	32.5	59.2	22.2	17.7
9	28.3	11.5	41.5	30.9	23.5	20.8	34.0	8.3	31.6	39.0	21.9	22.1	33.3	16.7	26.1	31.1	29.2	20.6	11.5	9.4	2.1	45.9	39.9	14.3	20.7
10	33.9	17.2	36.8	25.7	17.3	14.6	36.1	3.0	35.9	39.1	22.4	18.3	26.9	13.2	25.8	28.2	22.4	27.0	13.9	16.0	7.4	43.1	33.1	16.1	25.4
11	48.7	42.1	8.8	16.5	26.6	42.1	30.6	40.6	42.1	20.7	60.6	20.2	25.8	48.7	20.8	11.0	35.4	49.8	52.2	49.5	40.4	6.3	35.6	31.4	40.3
12	48.1	35.0	15.8	4.9	6.6	21.6	38.4	24.3	45.4	34.0	42.7	11.5	6.7	29.8	24.3	16.4	14.2	44.9	36.6	38.4	28.5	27.5	17.4	26.3	38.4
13	46.2	46.4	27.7	33.8	42.6	57.1	24.5	52.2	37.4	13.3	71.8	33.0	44.0	61.8	24.6	23.2	52.7	50.9	62.1	55.9	48.7	13.1	54.2	37.0	40.6

The distance from the planting base to the new alternative pre-cooling station

The maximum allowable delivery distance is less than 30km, i.e: d_{max}<=30

Assuming that the construction cost of each pre-cooling station is the same, that is, $\bar{c}$= 1.5million;
The transportation cost is 2 yuan/ton-kilometer, that is, c_{ij}=2

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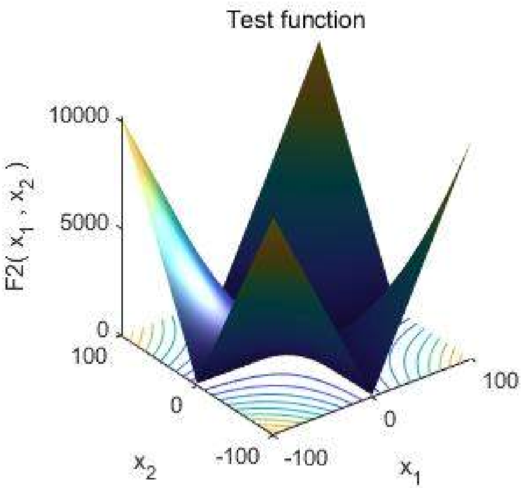
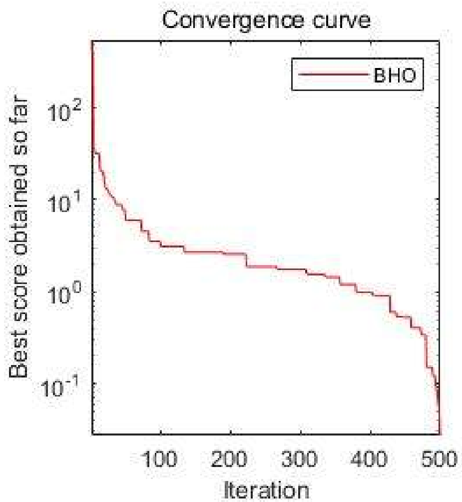
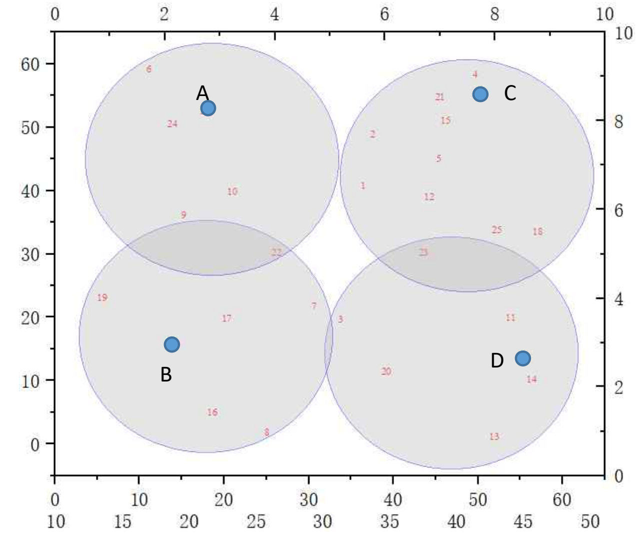
V. Result







No.	Distance from each planting point to the pre-cooling station								
A	9.3	4.4	13.2	16.7					
B	11.2	7.7	17.8	11.5	17.7	19.2			
C	3.0	4.7	5.9	14.3	11.5	20.1	17.4	21.6	22.9
D	22.3	6.3	16.3	3.8	13.1	20.2			

The model obtained by Matlab after 500 iterations of the alternative optimized points

Substituting the known parameters into the model, introducing the MIP, BHO and SVM algorithms, and solving by Matlab software, the optimal results can be derived, as shown in Fig.

$$\min \bar{c}\|\bar{x}\|_o + \min \sum_i \sum_j p_{ij} = 6{,}242{,}448.987 \text{ yuan}$$

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VI. Conclusion and limitation

- This study takes cold chain logistics first-mile network layout as the entry point, constructs a function model with total cost minimization and benefit optimization as the goal, and solves it by SVM and BHO algorithm, using test data for testing, and the verified the superiority of the models SVM, BHO, and MIP:
  - 4 points were selected from the original 25 alternative pre-cooling stations to build the pre-cooling station, achieving the purpose of reducing transportation and construction costs.
- Still, at the same time, many assumptions in the model will be affected by external influence in real life, such as vehicle speed, traffic conditions. The final calculation results using actual data are not yet known, so the model is still in the exploration stage and will continue to be studied and improved afterward.

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Appendix:

Part of the code

```
maxgen=2000;
starnumber=9;
trance=zeros(1,2000);
bestbh=zeros(2000,2);

for i=1:maxgen
    stars(i,:)=2*rands(1,2);
    fitness(i)=fun(stars(i,:));
end
[bh_fit,bh_row]=max(fitness);
X_bh=stars(bh_row,:);
for i=1:maxgen
    for j=1:starnumber
        newstars(j,:)=stars(j,:)+rand*(X_bh-stars(j,:));
        newfitness(j)=fun(newstars(j,:));
    end
    [starbest,index]=max(newfitness);
    if starbest>bh_fit
        bh_fit=starbest;
        X_bh=newstars(index,:);
    elseif starbest<bh_fit
        r=bh_fit/sum(newfitness);
        [compare,compare_index]=find((bh_fit-newfitness)<r);
        if ~isempty(compare_index)
            for k=length(compare)
                newstars(compare_index(k),:)=2*rands(1,2);
                newfitness(k)=fun(newstars(k,:));
            end
        end
        [starbest,index]=max(newfitness);
        if starbest>bh_fit
```

```
options.lk=-32*ones(1,d);   % lower bound
options.uk=32*ones(1,d);    % upper bound
options.m=50; % Size of the population
options.MAXITER=500; % Maximum number of iterations
options.n=length(options.uk);    % dimension of the problem.
options.ObjFunction=@Ackley; % the name of the objective function
options.Display_Flag=1; % Flag for displaying results over iterations
options.run_parallel_index=0;
options.run=10;

if options.run_parallel_index
    %     run_parallel
    stream = RandStream('mrg32k3a');
    parfor index=1:options.run
        %     tic
        %     index
        set(stream,'Substream',index);
        RandStream.setGlobalStream(stream)
        [bestX, bestFitness, bestFitnessEvolution,nEval]=BH_v1(options);
        bestX_M(index,:)=bestX;
        Fbest_M(index)=bestFitness;
        fbest_evolution_M(index,:)=bestFitnessEvolution;
    end
else
    rng('default')
    for index=1:options.run
        [bestX, bestFitness, bestFitnessEvolution,nEval]=BH_v1(options);
        bestX_M(index,:)=bestX;
        Fbest_M(index)=bestFitness;
        fbest_evolution_M(index,:)=bestFitnessEvolution;
    end
```

Thanks for your attention!