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A NETWORK FLOW MODEL OF REGIONAL TRANSPORTATION OF E-COMMERCE AND ANALYSIS ON MATURITY CHANGE OF FRESH FRUIT

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Abstract. *Fruit e-commerce with its huge development potential is attracting a large number of e-commerce giants. However, with the rapid development of fresh e-commerce, new challenges are emerging. In order to cope with the problem of vulnerability and difficult transportation of fresh fruit in the transportation process, this paper takes kiwi fruit as an example to analyze maturity change laws of fresh fruit after harvesting, and further analyze the change range of maturity of fresh fruit during transportation combined with regional transportation network. Finally, we regard the maturity change rate of fresh fruit as a variable of sensitivity analysis to observe the maturity change of fruits with different ripening rates when fruit is delivered, and then put forward suggestions for fruit farmers on the delivery decision-making, so as to provide theoretical basis of decision-making for the delivery, and improve the circulation efficiency of agricultural products.*
Keywords: Fresh fruit e-commerce, Regional transportation, Network flow model, Maturity change

1. **Introduction.** In recent years, with the improvement and popularization of third-party payment platform, fresh e-commerce has gradually become the important force of e-commerce development in China [1]. Fresh fruit is perishable, vulnerable and later ripening, and the quality of fresh fruit is closely related to maturity. Generally speaking, farmers lack the understanding of maturity change in the process of transportation, which makes it difficult for fruit farmers to make accurate and effective delivery decision, resulting in the quality of fresh fruit received by customers is difficult to be maintained. Therefore, it is an urgent problem in the field of fresh fruit logistics to help fruit farmers who engaged in e-commerce to make decision on picking and delivery according to the change law of maturity during transportation, so as to improve the quality of fresh fruit and reduce the losses of fruit farmers caused by the damage of fresh fruit. Only by fundamentally improving the quality of fruit can we promote the sustainable development of fresh e-commerce.

Network flow is a theoretical method of graph theory, which is widely used in various fields such as communication, transportation, engineering planning, task assignment and

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computer aided design (CAD). In order to make the process of fresh fruit transportation clearer, we first separate key transportation nodes in the process of transportation according to the logistics process of the existing e-commerce platform, then apply the network flow theory to describing the process of fresh fruit transportation from delivering to receipt, and finally network flow charts on whole process of fresh fruit transportation are presented.

Then, we take kiwi fruit as an example to study the maturity change law of fresh fruit, and combine it with the network flow charts mentioned above to observe the maturity change in the transportation process. In order to expand scopes of this study, we take speed of maturity change as a variable to carry out sensitivity analysis. Finally, delivery intervals of different fresh fruits with different ripening rates are obtained, and some maturity-based delivery suggestions are put forward for fruit farmers.

Our special contribution is that we introduce network flow theory into the analysis of e-commerce fulfillment and formulate a general methodology to analyze the maturity change of fresh fruit in regional transportation. On the one hand, we focus on the physiological characteristics of fresh fruit to study the quality changes of fresh fruit in the process of transportation, which provides a new perspective for fresh fruit transportation and enriches the research of fresh fruit transportation theory. On the other hand, by applying the change law of fresh fruit maturity to the transportation process, the damage of fresh fruit in transportation can be reduced, the loss of fruit farmers can be further reduced, and the sales revenue of fruit farmers can be finally increased. Simultaneously, by studying the change law of maturity in the transportation process, we can provide theoretical support for the delivery decision of fruit farmers, improve the circulation efficiency of agricultural products, and further promote the realization of e-commerce for poverty alleviation.

The rest of paper is organized as follows. A brief review on related advances is presented in Section 2. Section 3 describes the network flow model and maturity change law in the process of fruit transportation, builds one corresponding mathematical model, and gives the solution method. In Section 4, taking kiwi fruit as an example, numerical experiment is carried out, and through the sensitivity analysis, the maturity intervals of different kinds of fruits are obtained. Finally, Section 5 discusses the empirical results and some future insights.

2. Literature Review.

The freshness of fresh produce is closely related to food safety, and it is also one of important indicators to measure the quality of fresh produce. The freshness of perishable fresh agricultural products is extensively studied, such as freshness monitoring [2,3], transportation [4] and vehicle route optimization (VRP) considering freshness [5,6]. Ruan and Shi [7] put forward the idea of monitoring and evaluating the freshness of fresh fruit in the process of distribution through the Internet of Things (IoT), which can automatically obtain the optimal distribution environment of different distribution scenarios according to historical distribution data. Battery less radio frequency sensor can accurately predict vegetable freshness by measuring the temperature and humidity of storage environment [8]. By constructing a vehicle path model with a time window, Amorim and Almada-Lobo [9] point out that large time windows lead to less spoilage, considering the freshness of fresh produce. Ahumada and Villalobos [10] consider the freshness and operating costs, and propose a joint operation optimization model of fresh produce harvesting and distribution. It can be observed from the above literature that controlling the freshness during transportation is beneficial to delay the deterioration rate of agricultural products and reduce damage costs.

Since the freshness of agricultural produce changes rapidly, cold chain logistics is often applied to reducing the rate of deterioration during transportation. Research on cold chain transportation is now quite extensive, including cold chain distribution route optimization [11], cold chain technology [12] and its impact on the environment. In order to lower the losses of fresh fruit and vegetables in the distribution, Raut et al. [13] evaluate the cold chain third-party logistics (CTPLs), and conclude that the refrigerator and loading capacity, knowledge and information technology management are the most significant factors for selection of CTPLs. The occurrence of food waste may be reduced by managing and monitoring the temperature properly during cold chain transportation. Therefore, cold chain logistics can effectively reduce the postharvest losses of perishable produces, and ensure the quality of products received by customers [14].

However, cold chain logistics is costly and cold chain facilities are not well equipped in some areas of China. Thus, most of fresh fruits are difficult to be transported in cold chain throughout. Therefore, research on the maturity change during the transportation of fresh fruit is expected to reduce distribution costs and damage rate of fresh fruit. Sun et al. [15] experiment with lemon, pointing out that the harvest maturity of lemon affects its shelf life and quality. Tu et al. [16] develop an intelligent picking robot, which can not only detect passion fruit, but also automatically classify passion fruit according to its mature stage with high accuracy. Fruit maturity detection technology is constantly innovating and developing, such as the change from destructive detection to non-destructive detection, from inaccuracy to accuracy, and from high cost to low cost. Compared with traditional detection methods, imaging technology is non-destructive, environmentally friendly, reliable, accurate and simple, and it is successfully implemented to the evaluation of fruit maturity stage [17]. Prasad et al. [18] propose that the lack of knowledge on maturity, harvesting period and post-harvest management is the main cause of postharvest loss of fresh fruit. The fruit quality can be predicted and the loss caused by the damage of fresh fruit can be effectively reduced by introducing the maturity change rule of fruit into the distribution process [19]. For some fruits, firmness declines with maturity [20], and fruits with different harvesting period and harvesting maturity have different storage temperature and life [21].

Freshness indicates the fresh degree of fruits, but fruits with high freshness may not be suitable for transportation. It can be seen that, compared with freshness, considering fruits maturity during transportation can predict fruits quality more accurately and reduce fruits damage during transportation. Therefore, it is necessary for us to study the changes of fruits maturity during the transportation period, and to determine the transportation schemes of different fruits according to the ripening characteristic and rule of fresh fruits, so that the best quality of fruits can be maintained when shipped to customers. Thus, occurrence of returning and losses of fruits will be reduced, and the profit of fruit farmers will be improved.

3. Problem Statement and Mathematical Model.

3.1. **Network flow theory.** A network flow refers to a directional network diagram formed by a plurality of nodes and nodes connected to each other. In general, a directed graph is represented by $G(V,E)$, where V represents a set of all nodes, $V = v_1, v_2, \ldots, v_m$, and E represents a set of arcs formed by interconnections between nodes, $E = e_1, e_2, \ldots, e_n$, the arc e is represented by an ordered pair (i,j), where $i,j \in [1,m]$, $e(i,j)$ indicates that the direction is from i to j, and:

$$e(i,j) = \begin{cases} 0 & \text{There is an arc pointing from } i \text{ to } j \\ 1 & \text{Otherwise} \end{cases} \tag{1}$$

In the directed graph $G(V, E)$:

1) There is only one source point S (the source point in this article refers to fruit farmers);

2) There is only one end point T (in this article, the end point refers to the terminal consumers);

3) Each arc in the graph has a non-negative time, indicating the transportation time between the two nodes.

The graph $G(V, E)$ that satisfies the above three conditions simultaneously is called a network flow graph. The weight t_{ij} between the nodes in the network flow graph is used to represent the time required for transportation between the two nodes, $t_{ij} > 0$. Therefore, a complete network flow graph is represented by $G(V, E, t)$, where $t = \{t_{ij}, i, j = 1, 2, \ldots, m\}$.

3.2. **Network flow model.**

3.2.1. *Problem definition.* According to the transportation distance, fresh fruit transportation can be divided into two types: cross-regional transportation and regional transportation. The process of cross-regional transportation under the e-commerce environment is much more complicated than that of regional transportation in the real world, including the diversification of transportation modes and the increase of transportation links. Zhang et al. [22] propose that fresh products need to be transported by rail and maritime transportation mode in long-distance transportation, and compare the profits obtained by different transportation modes under decentralized supply chain and centralized supply chain, pointing out that the profit of railway transportation is higher than that of sea transportation under the same risk. Meanwhile, the external environment of different regions is quite different, which makes the change of fresh fruit maturity more complex and uncertain. Therefore, this paper mainly focuses on the regional transportation process of fresh fruit. Through the analysis of the transportation process in one region, the flow chart of fresh fruit transportation in one region is shown in Figure 1. The intermediate transportation stations are collectively referred to as transit stations, which

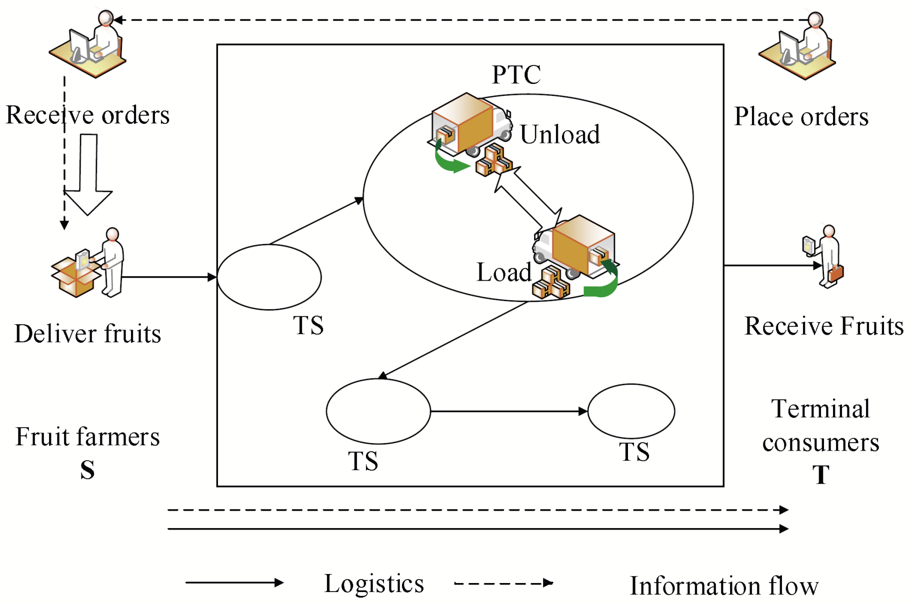

FIGURE 1. Basic flow chart of fresh fruit transportation in the region

are represented by TS, and among of them the primary transit center is represented by PTC.

As shown in Figure 1, customers place orders online through the network terminal, and fruit farmers receive the orders information through computer terminal, then fruit farmers (S) pick and pack fruits according to the customer's orders quantity to deliver them. Fruits are transported to customers (T) through a number of transit stations (TS). Here, the regional scope refers to a coverage of one PTC (intra-provincial transportation).

3.2.2. *Model parameters and assumption.* In order to increase the readability of the article, we explain the parameters used in the article, as shown in Table 1 (DT is an abbreviation of delivery terminal, and RT is an abbreviation of receiving terminal).

Table 1. Description of main parameters

Symbol	Meaning	Symbol	Meaning
T_a	Central warehouse	R_D	Distribution center
D_R	Delivery station	S	Fruit farmers
D_O	Primary transit center	T	Terminal consumers
D_t	Secondary transit center of DT	R_B	Truck freight station of RT
D_B	Truck freight station of DT	R_{t1}	Secondary transit center of RT

Transportation time between two nodes is represented by t_{ij}, i represents the former node and j represents the latter node. In order to facilitate the analysis, two basic hypotheses are proposed in this paper.

Hypothesis 1: Maturity of fresh fruit is mainly affected by transportation time. That is, it is assumed that fresh fruit is in a stable cold chain environment during transportation.

Hypothesis 2: The residence time of fresh fruit at the transit station can be neglected in the transportation process, because the residence time is relatively short compared to the transportation time.

3.2.3. *Construction of network flow model.* By analyzing the characteristics of transportation within one region, it is found that there are five key stations in the whole transportation process, that is: delivery station, secondary transit center of delivery terminal, regional primary transit center, secondary transit center of receiving terminal, and distribution center.

Central warehouse refers to a warehouse for storing fresh fruits provided by fruit farmers. After receiving orders online, fruits will be picked and packed by warehouse administrators according to orders requirement. Then, the packed fruits are delivered to express companies for transportation. Therefore, regional transportation can be divided into two types: regional transportation with central warehouse and regional transportation without central warehouse, according to whether there is a central warehouse in a region.

1) A network flow model without central warehouse in a region

Transportation processes of orders generally pass through only one primary transit center in one region. Compared with cross-regional transportation, there are relatively fewer transit stations. In one region, fruits are usually transported by means of truck due to short distance, and railway and air transportation are not often required (except the remote areas). According to the survey, the network flow model of fresh fruit transportation without central warehouse can be obtained as shown in Figure 2. The main process is as follows.

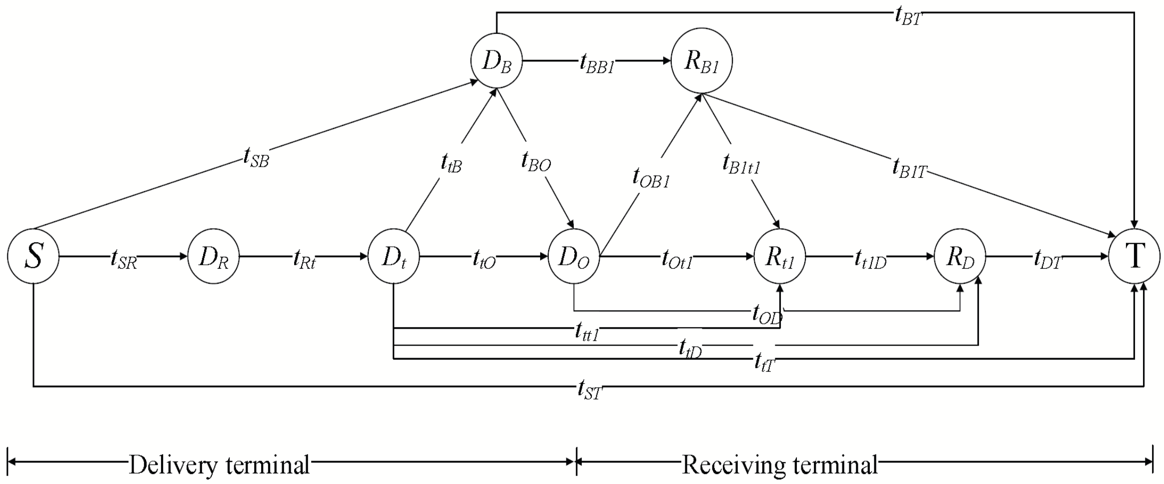

FIGURE 2. Network flow model of regional transportation without central warehouse

a) Fruit farmers (S) who engaged in e-commerce hand over fresh fruits to delivery station (D_R), further fruits will be transported in the order of secondary transit center of delivery terminal (D_t), primary transit center (D_O), secondary transit center of receiving terminal (R_{t1}), distribution center (R_D) and consumers (T) (this process is also known as trunk line transportation); another transportation process is that after fruits are transported from D_t to truck freight station of delivery terminal (D_B), they can be transported in the order of trunk line transportation process; If it is unnecessary to pass through primary transit center in one region, fruits will be transported directly from secondary transit center of the delivery terminal (D_t) to secondary transit center of the receiving terminal (R_{t1}), then fruits are distributed to the customers (T) through distribution center (R_D).

b) When fruit farmers sell large quantities of fruits, they do not want to transport fruits by express, so logistics companies and self operated vehicles become better transportation scheme. Fruit farmers (S) directly transport large quantities of fresh fruits to truck freight stations of delivery terminal (D_B), and then fruits are transported by trucks to freight stations of receiving terminal (R_{B1}). Further, fruits can be directly transported to the consumer (T) that is close to the R_{B1} by trucks. For customers far away from D_B and R_{B1}, fruits should be transported to consumers (T) through some transit stations, for example, D_O, R_{t1}, R_D. Of course, fruit farmers can transport fruits to consumers (T) by self operated trucks.

2) A network flow model with central warehouse in a region

Transportation in an area with a central warehouse means that a warehouse for storing fresh fruit is placed within one region. When fruits need to be delivered, fruit farmers (S) directly allocate fruits from central warehouse. In this case, there is only one delivery center, and generally there is no secondary transit center in the delivery terminal. When fruit farmers receive orders, fruits are delivered from central warehouse. The network flow model is shown in Figure 3.

Obviously, central warehouse will reduce transportation time and increase correspondingly storage time of fruits. In the early period, fruit farmers (S) transport fruits to central warehouse for storage. When fruit farmers receive orders, fruits are sorted and packed in central warehouse (T_a). Subsequently, staff of central warehouses will deliver packed fruits to delivery station (D_R), further fruits will be transported in the order of primary transit center (D_O), secondary transit center of receiving terminal (R_{t1}), distribution center (R_D) and consumers (T) (this process is also known as trunk line transportation).

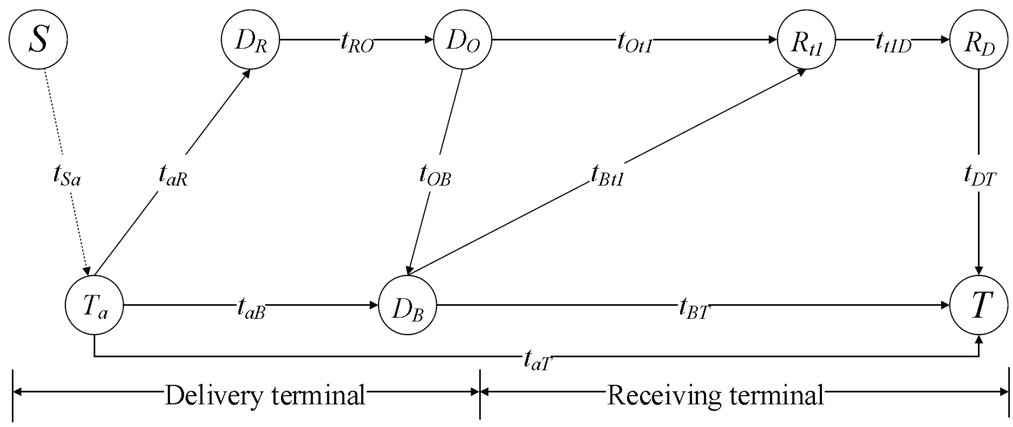

FIGURE 3. Network flow model of regional transportation with central warehouse

Of course, fruits may be transported to consumers (T) through truck freight stations of delivery terminal or self operated trucks.

3.3. **Analysis of fresh fruit maturity change.** Maturity change of fresh fruit is not simply affected by external environment such as temperature, humidity and oxygen content, but also characteristics of fruits itself. Moshiur et al. [23] experimentally verifiy that the same inclusion of fruits picked at different maturity stages has different change trends. The maturity of fresh fruits is affected by various complex factors in reality, and the maturity change laws of different kinds of fresh fruits are also very different. However, maturity in the process of cold chain transportation is mainly affected by transportation time and characteristics of fruit itself after harvesting. Therefore, it is assumed that maturity of fresh fruit is a function of transportation time, and simultaneously in the numerical analysis the change rate of maturity is taken as a variable of sensitivity analysis to analyze the influence of maturity on delivery schemes of different types of fruits.

The maturity of fruit generally includes harvestable maturity, edible maturity and physiological maturity. Harvestable maturity refers to growth and accumulation of nutrients of fruits are completed, so fruits that have reached the harvestable maturity can be picked at any time in the future. Fruits that have just reached the harvestable stage are not completely suitable for fresh eating, but suitable for long-term storage and long-distance transportation. Edible maturity refers to that fruits have reached edible mature level, but fruits harvested at this stage are mostly suitable for nearby sales, processing or short-distance transportation. Physiological maturity shows that fruits are fully mature and no longer suitable for storage and transportation. The harvestable period of most fruits is before the edible period, but there are also cases in which harvesting period and edible period are in the same period for a small number of fruits. These fruits are not suitable for transportation and can only be sold nearby (such as nearby farmers' markets, residential areas). Therefore, we will not study the distribution process of such fruits in this paper, and mainly focus on the fruit that harvestable period is before edible period.

Fruit's ripening process is shown in Figure 4 [18]. Fruits are not fully grown in the non-harvesting stage, and the nutrients and tastes have not reached eating standard, so it cannot be picked; when maturity is between the harvesting maturity and the edible maturity, the changes of various nutrient indicators are relatively stable (harvesting stage), fruits at this stage are suitable for transportation and storage; fresh fruits will undergo a respiratory jump immediately after reaching edible maturity, and various nutrient indicators change rapidly, resulting in maturity changes rapidly. Fruit spoils easily and cannot

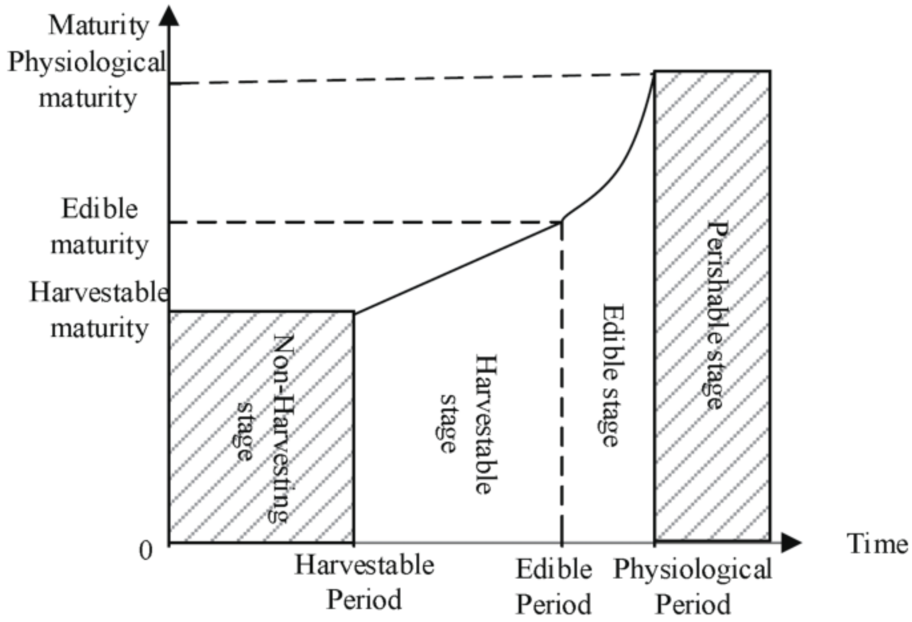

FIGURE 4. Schematic diagram of the stage of fruit maturity change

be transported over long distances after edible period. Therefore, this paper mainly studies the stage when the maturity reaches the pre-edible maturity (that is, the harvestable stage).

In order to quantify maturity of fruit, we assume that there are L indicators that affect the maturity of fruit, and indicators content increases with time (if some indicators are negatively correlated with time, they can be transformed into positive correlation by function transformation, such as $b' = \frac{1}{b}$). In harvestable stage of fruit, content of each indicator is represented by $b_p^1, b_p^2, b_p^3, \ldots, b_p^L$; and in edible stage of fruit, content of each indicator is represented by $b_e^1, b_e^2, b_e^3, \ldots, b_e^L$; when physiological maturity is reached, the content of each indicator is expressed as $b_r^1, b_r^2, b_r^3, \ldots, b_r^L$; when calculating maturity of fruit, weight of each indicator is represented by $w_1, w_2, w_3, \ldots, w_L$, respectively. Here we assume that the maturity of the fruit reaches 100% at the physiological maturity stage. Maturity of fresh fruit at a certain period is measured by the ratio of weighted average of all relative indicator contents during this period to weighted average of indicators contents at the time of physiological maturity.

According to the above analysis, maturity of fresh fruit is represented by the symbol F, physiological maturity F_r is 100%, as shown in Formula (2):

$$F_r = \frac{w_1 b_r^1 + w_2 b_r^2 + w_3 b_r^3 + \cdots + w_L b_r^L}{w_1 b_r^1 + w_2 b_r^2 + w_3 b_r^3 + \cdots + w_L b_r^L} \times 100\% = 100\% \tag{2}$$

Then, the picking maturity of fresh fruit (F_p) and just reaching the edible stage (F_e) are shown in Formula (3) and Formula (4) respectively:

$$F_p = \frac{w_1 b_p^1 + w_2 b_p^2 + w_3 b_p^3 + \cdots + w_L b_p^L}{w_1 b_r^1 + w_2 b_r^2 + w_3 b_r^3 + \cdots + w_L b_r^L} \times 100\% \tag{3}$$

$$F_e = \frac{w_1 b_e^1 + w_2 b_e^2 + w_3 b_e^3 + \cdots + w_L b_e^L}{w_1 b_r^1 + w_2 b_r^2 + w_3 b_r^3 + \cdots + w_L b_r^L} \times 100\% \tag{4}$$

Since $b_p^l < b_e^l < b_r^l$, $l = 1, 2, \ldots, L$, it can be seen that $0 < F_p < F_e < F_r = 100\%$.

As mentioned above, before maturity of fresh fruit reaches edible maturity, change trends of various indexes are relatively stable. Therefore, change rate of maturity of fresh fruit can be calculated by changes of various indexes in fruits from picking period to just reaching edible maturity. If fruits are picked at harvestable maturity, the time from picking to reaching the edible minimum maturity is t_c days, then the average hourly change rate of the maturity f_{ave} is as shown in Formula (5):

$$f_{ave} = \frac{w_1\left(b_e^1 - b_p^1\right) + w_2\left(b_e^2 - b_p^2\right) + w_3\left(b_e^3 - b_p^3\right) + \cdots + w_L\left(b_e^L - b_p^L\right)}{24t_c\left(w_1 b_r^1 + w_2 b_r^2 + w_3 b_r^3 + \cdots + w_L b_r^L\right)} \times 100\% \tag{5}$$

During transportation, if total transportation time is t_T hours, in order to ensure quality of fresh fruits when they reach the hands of consumers, we take the edible maturity as the best maturity when customers receive them, so maturity of fresh fruits when fruit farmers delivery (F_S) is as shown in Formula (6):

$$F_S = F_e - f_{ave} \times t_T \tag{6}$$

In order to help fruit farmers determine the best maturity range for delivering, it is also necessary to calculate maturity change range in the transportation process. Therefore, we need to further build a mathematical model of fresh fruit transportation in a region considering maturity to get the range of maturity changes in the transportation process, determine the best maturity for fruit farmers to delivery and achieve goals of reducing cost of damaged goods and improving customers satisfaction.

3.4. **Mathematical model.** The maturity change of fruit and transportation time have important impacts on the quality of fresh fruit [19]. In order to ensure quality of fresh fruit purchased by customers, this part combines rate of maturity change with the time required in the transportation process, and constructs the regional transportation mathematical model to find out the optimal route and corresponding range of maturity change during transportation. As mentioned before, in the process of transportation, maturity's change rate in cold chain transportation is relatively stable for fresh fruits. It can be considered that change of maturity is a function of transportation time and increases with time. Therefore, decision-making goal of the model is to minimize the change of maturity in the process of transportation to ensure quality of fresh fruit. According to the above analysis, mathematical model is as follows:

Objective function:

$$Min\ Z = \sum_{i=1}^{m}\sum_{j=1}^{m} f_{ave} t_{ij} x_{ij} \tag{7}$$

Constraints:

$$\sum_{j=2}^{m} x_{1j} = 1 \tag{8}$$

$$\sum_{i=1}^{m-1} x_{im} = 1 \tag{9}$$

$$\sum_{i=1}^{m} x_{ik} - \sum_{j=1}^{m} x_{kj} = 0 \quad \forall k = 2, 3, 4, \ldots, m-1. \quad i \neq k, \quad k \neq j \tag{10}$$

$$t_{ij} > 0 \quad \forall e(i,j) = 1 \tag{11}$$

$$x_{ij} = \begin{cases} 1 & \text{If vehicles pass through } i \text{ and } j \text{ node, the value is 1} \\ 0 & \text{Otherwise} \end{cases} \tag{12}$$

In order to minimize maturity change in the transportation process objective function (7) is proposed; constraint (8) means that fruit must be transported from the first node S (fruit farmers); constraint (9) indicates that transportation of fruit must end at consumers T; constraint (10) shows that transportation process must continue from the same transit station after arriving at a transit station; constraints (8)-(10) ensure that the transportation process is a feasible route; constraint (11) indicates that if there is a directed arc between two nodes of i and j, the transportation time is positive; constraint (12) defines a decision variable x_{ij}, the value is 1 if transportation process passes through i and j, otherwise it is 0.

According to the above analysis, if total transportation time of fresh fruit is $\sum_{i=1}^{m}\sum_{j=1}^{m} t_{ij}x_{ij}$ hours, then Formula (6) can be converted into Formula (13):

$$F_S = F_e - f_{ave}\sum_{i=1}^{m}\sum_{j=1}^{m} t_{ij}x_{ij} \tag{13}$$

In the network flow model, due to different transportation links and routes, transportation time required and maturity change of fresh fruit are also quite different. So it is necessary to find out the maximum and minimum of maturity changes in the process of transportation, in order to obtain range of maturity change. The above process only gives a mathematical model for the minimum value of maturity change. However, objective function of the maximum value of maturity change is opposite of Formula (7), which will not be discussed here.

3.5. **Solution method of model.** In this paper, Floyd algorithm is used to solve the above model. Floyd algorithm is a kind of algorithm used to find the shortest path of each pair of vertices [24]. It constructs time matrices $T(0), T(1), T(2), \ldots, T(m)$ of graphs successively by directly inserting vertices into the weighted adjacency matrix of the network flow graph. At the same time, a subsequent point matrix is introduced to record the shortest path between two points, also known as the interpolation point method.

4. **Numerical Experiment and Results Analysis: A Case Study of Kiwi Fruit.** Because maturity measurement indicators of different kinds of fresh fruits are quite different, it is difficult to measure with unified indicators for all fruits, so this paper takes kiwi fruit as an example to verify the proposed model and algorithm. It is hoped that the research results can provide decision support for fruit farmers who are engaged in e-commerce and reduce damage of fruit.

At present, there are plenty of researches on kiwi fruit maturity in the field of agricultural science. Scholars generally believe that content of soluble solids in kiwi fruit is the main index to measure its maturity change [25]. Liu et al. [19] prove that time and temperature have important influences on the change of soluble solid content through multiple linear regression. Guo et al. [26] point out that soluble solid is an important factor to determine maturity of kiwi fruit, and propose a non-destructive detection method of soluble solid content. Considering the restriction of subject, this paper does not research on measurement method of kiwi fruit inclusions, and mainly conducts numerical test and result analysis on the basis of the experimental data of Chen et al. [25].

According to post harvest change data on soluble solids of kiwi fruits of Chen et al., the maturity can be caculated and change trends of maturity of different kinds of kiwi fruits (Shanyang No.1 and Apple type) are obtained respectively, as shown in Figure 5.

From Figure 5, it can be observed that maturity change trends of two different kiwi fruit are roughly the same: at early stage, change of maturity is relatively slow, and at the

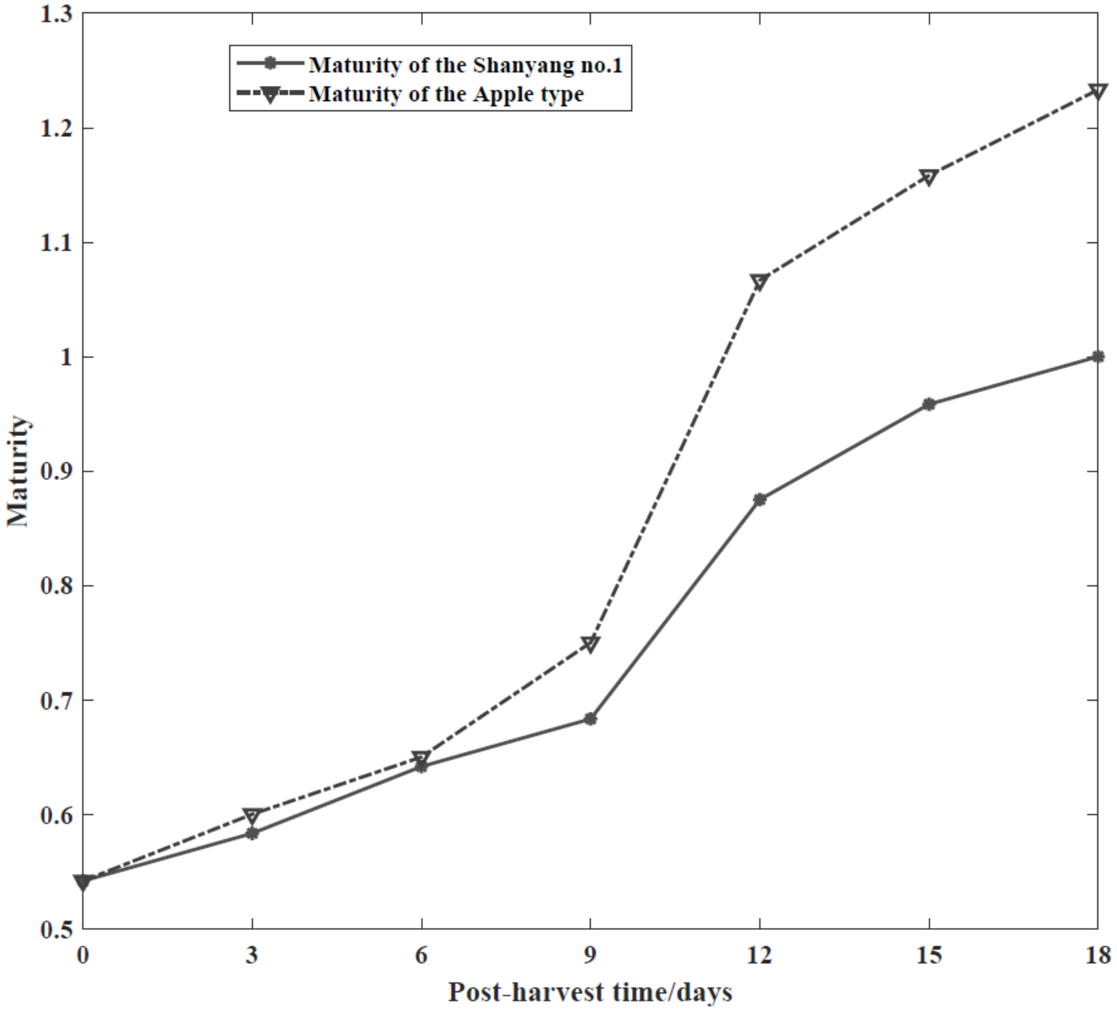

FIGURE 5. Maturity change of kiwi fruits after harvesting

later stage change of maturity is relatively fast. The maturity of kiwi fruit harvested with soluble solids content of 6.5% changes slowly within 9 days after harvesting. However, after more than 9 days, with occurrence of respiratory jump, maturity and softening speed of kiwi fruit change rapidly, kiwi fruit are no longer suitable for long-distance transportation. By analyzing postharvest maturity changes of different varieties of kiwi fruit, we find that the postharvest maturity of Apple type kiwi fruit changes faster than that of Shanyang No.1. In order to clearly observe range of maturity changes during transportation, here we take Apple kiwi fruit as an example for analysis.

When the content of soluble solids (soluble sugars) is 6.5%, kiwi fruit reaches to the harvestable maturity, and basically meets requirements of eating; when the content of soluble solids is 9.0%, kiwi fruit reaches edible maturity, it has a better taste than before and will soon reach the best taste; when it is more than 12.0%, it reaches the physiological maturity, and tastes best. Therefore, we set the weight of soluble solids as 100%. From the experimental data of Chen et al., it can be observed that the kiwi fruit is picked when soluble solids content reaches 6.5%. Then according to the maturity measurement method proved in this paper, it can be concluded that harvestable maturity is 54.17%, that is:

$$F_p = \frac{100\% \times 6.5\%}{100\% \times 12\%} \times 100\% = 54.17\% \tag{14}$$

After 9 days of harvesting, edible maturity is reached, and content of soluble solids is about 9.0%, so maturity of kiwi fruits at this moment is 75.00%, that is:

$$F_e = \frac{100\% \times 9\%}{100\% \times 12\%} \times 100\% = 75.00\% \tag{15}$$

Then, according to Formula (5), the rate of maturity changes is 0.096% per hour, that is:

$$f_{ave} = \frac{100\% \times 9\% - 100\% \times 6.5\%}{24 \times 9 \times 100\% \times 12\%} \times 100\% = 0.096\% \tag{16}$$

However, in the process of fresh fruit transportation, maturity change is not only affected by the above rate of change, but also transportation time and routes. In order to determine change range of fresh fruit's maturity under different transportation situations, it is necessary to solve e-commerce transportation model to analyze and discuss change range of maturity, and further put forward effective suggestions to help fruit farmers pick and deliver it.

4.1. **Solution of model.** In this section, the transportation network flow model of fresh fruit is solved according to Floyd algorithm. First of all, the transportation time in the existing e-commerce platform is investigated and analyzed, and then the driving time between adjacent stations of the network flow under different situations is assigned. Finally, the network flow model is solved using MATLAB software, and the optimal maturity change is obtained.

4.1.1. *Regional transportation without central warehouse.* First, we assign values to directed arcs in Figure 2 according to the survey data. Subsequently, Floyd algorithm is used to solve our model. Driving time and transportation routes between S and T obtained are as shown in Figure 6 where the bold solid line represents the longest route and the dotted line represents the shortest route.

By solving network flow chart, we can get that all the routes are as shown in Table 2 (MC is maturity change during transportation). Among them, the longest transportation time is 26 hours, and the maximum maturity change during transportation is 2.5%. The longest path is: $S \to D_R \to D_t \to D_B \to D_O \to R_{B1} \to R_{t1} \to R_D \to T$, that is: fruit

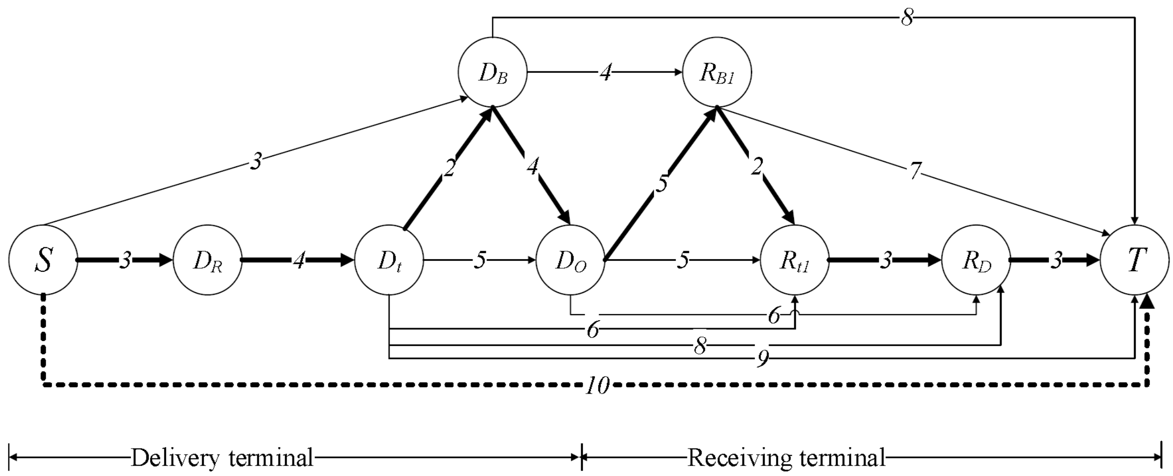

Figure 6. Regional transportation path without central warehouse where the number on the arrow indicates transportation time of adjacent nodes (unit: hour)

TABLE 2. All routes of regional transportation without central warehouse

No	Routes	Time (h)	MC	F_S
1	$S \to D_R \to D_t \to D_O \to R_{B1} \to R_{t1} \to R_D \to T$	24	2.30%	72.70%
2	$S \to D_R \to D_t \to D_O \to R_D \to T$	24	2.30%	72.70%
3	$S \to D_R \to D_t \to D_O \to R_{t1} \to R_D \to T$	22	2.11%	72.89%
4	$S \to D_R \to D_t \to D_O \to R_D \to T$	20	1.92%	73.08%
5	$S \to D_R \to D_t \to D_B \to D_O \to R_{B1} \to R_{t1} \to R_D \to T$	26	2.50%	72.50%
6	$S \to D_R \to D_t \to D_B \to D_O \to R_{B1} \to T$	25	2.40%	72.60%
7	$S \to D_R \to D_t \to D_B \to D_O \to R_{t1} \to R_D \to T$	23	2.21%	72.79%
8	$S \to D_R \to D_t \to D_B \to D_O \to R_D \to T$	21	2.02%	72.98%
9	$S \to D_R \to D_t \to D_B \to R_{B1} \to R_{t1} \to R_D \to T$	20	1.92%	73.08%
10	$S \to D_R \to D_t \to D_B \to R_{B1} \to T$	20	1.92%	73.08%
11	$S \to D_R \to D_t \to D_B \to T$	17	1.63%	73.37%
12	$S \to D_R \to D_t \to R_{t1} \to R_D \to T$	18	1.73%	73.27%
13	$S \to D_R \to D_t \to R_D \to T$	17	1.63%	73.37%
14	$S \to D_R \to D_t \to T$	16	1.54%	73.46%
15	$S \to D_B \to D_O \to R_{B1} \to R_{t1} \to R_D \to T$	19	1.82%	73.18%
16	$S \to D_B \to D_O \to R_{B1} \to T$	19	1.82%	73.18%
17	$S \to D_B \to D_O \to R_{t1} \to R_D \to T$	17	1.63%	73.37%
18	$S \to D_B \to D_O \to R_D \to T$	15	1.44%	73.56%
19	$S \to D_B \to R_{B1} \to R_{t1} \to R_D \to T$	14	1.34%	73.66%
20	$S \to D_B \to R_{B1} \to T$	14	1.34%	73.66%
21	$S \to D_B \to T$	11	1.06%	73.94%
22	$S \to T$	10	0.96%	74.04%

farmers S send fruits packed to delivery center (D_R); and then fruits are transported to the secondary transportation center of the delivery terminal (D_t); Since D_t is far away from the primary transit center (D_O), fruits are transported to D_O via truck freight station (D_B); fruits are transported further from D_O to the secondary transit center of the receiving terminal (R_{t1}) through truck freight station of the receiving terminal (R_{B1}); finally fruits are distributed to consumers (T) through distribution center (R_D). The shortest transportation time is 10 hours, and the minimum maturity changes by 0.96% in transportation. The shortest path is: $S \to T$, that is, farmers (S) directly transport fruits to consumers (T) through their own vehicles without any intermediate links, which is only applicable to the same city distribution or large-scale wholesale.

Through the analysis of above, it can be concluded that in the process of regional transportation without central warehouse, if maturity of kiwi fruit delivered by fruit farmers is in the range of $[72.5\%, 74.04\%]$, the kiwi fruit can be guaranteed to be near the edible maturity when they reach customers, which will not lead fruit to be over ripening or too raw.

4.1.2. *Regional transportation with central warehouse.* The central warehouse is generally used to store fruit picked in advance. However, due to the inconsistency between the prediction of fruit sales and the actual demand, storage time of fresh fruit in the central warehouse is uncertain. The storage time may be long, even longer than the transportation time from farmers to central warehouse. Simultaneously fruits are delivered from the central warehouse. Therefore, when solving the transportation model with a central warehouse, transportation time from farmers to the central warehouse and storage time in the central warehouse are not considered.

Next, the model with the central warehouse will be solved. First, the network flow is assigned according to transportation time data on e-commerce platform. Second, the optimal transportation routes are calculated by Floyd algorithm, as shown in Table 3 (MC is maturity change during transportation). In Figure 7, the solid line represents a route with the largest maturity change, while the dotted line represents the route with the smallest maturity change. Depending on the calculation results: the maximum transportation time is 19 hours, and maturity change is 1.82%. The longest path is: $T_a \to D_R \to D_O \to D_B \to R_{t1} \to R_D \to T$. The central warehouse (T_a) is responsible for sending fruits to delivery station (D_R) when farmers receive online orders. Then fruits are transported to the primary transit center (D_O) by truck. Since D_O is far away from the secondary transit center of the receiving terminal (R_{t1}), if the fruit is directly transported to R_{t1}, it will increase the transportation cost. It is necessary to sort the fruit at truck freight station (D_B), and then the fruit will be transported to R_{t1}. Finally, fruits are distributed to consumers (T) through the distribution center (R_D). However, the shortest transportation time is 4 hours, and maturity change is 0.38%. The shortest path is: $T_a \to T$, that is, fruit is transported from central warehouse (T_a) to the consumers (T) by their own logistics, which is suitable for the same city distribution scenario or large-scale wholesale.

Through the analysis of above, it is concluded that during regional transportation with the central warehouse, when maturity of kiwi fruit is in the interval $[73.18\%, 74.62\%]$, kiwi fruit received by people can reach the best taste.

TABLE 3. All routes of regional transportation with central warehouse

No	Routes	Time (h)	MC	F_S
1	$T_a \to D_R \to D_O \to D_B \to R_{t1} \to R_D \to T$	19	1.82%	73.18%
2	$T_a \to D_R \to D_O \to D_B \to T$	13	1.25%	73.75%
3	$T_a \to D_R \to D_O \to R_{t1} \to R_D \to T$	16	1.54%	73.46%
4	$T_a \to D_B \to R_{t1} \to R_D \to T$	12	1.15%	73.85%
5	$T_a \to D_B \to T$	6	0.58%	74.42%
6	$T_a \to T$	4	0.38%	74.62%

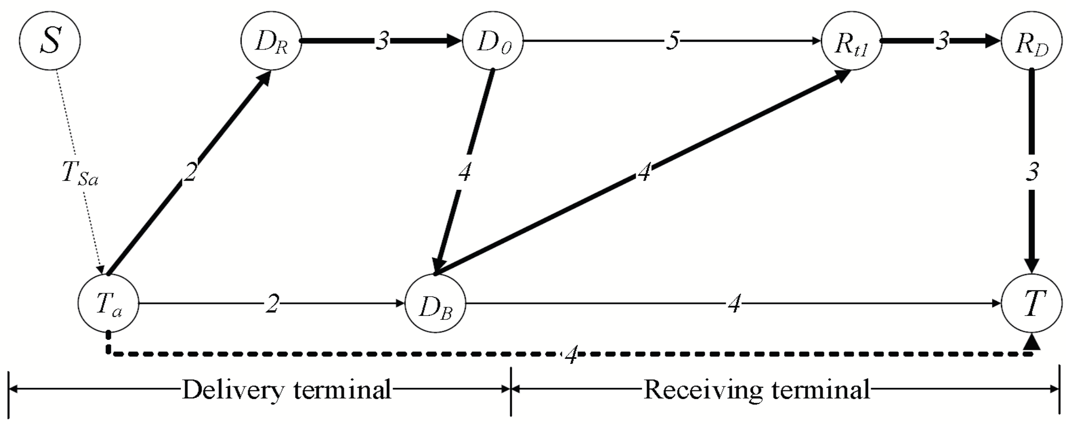

FIGURE 7. Regional transportation path with central warehouse where the number on the arrow indicates the transportation time of adjacent nodes (unit: hour)

4.2. **Sensitivity analysis.** In order to further analyze influence of maturity change on harvest and delivery decision-making of fruit farmers, sensitivity analysis with average daily change rate of maturity is carried out in this part. Based on maturity change rate of 0.096% per hour (average daily change rate of 2.31%), we take 0.5% as increment of maturity daily average change rate to conduct sensitivity analysis combined with regional transportation process without central warehouse. Sensitivity analysis results of delivery maturity interval are obtained, as shown in Figure 8.

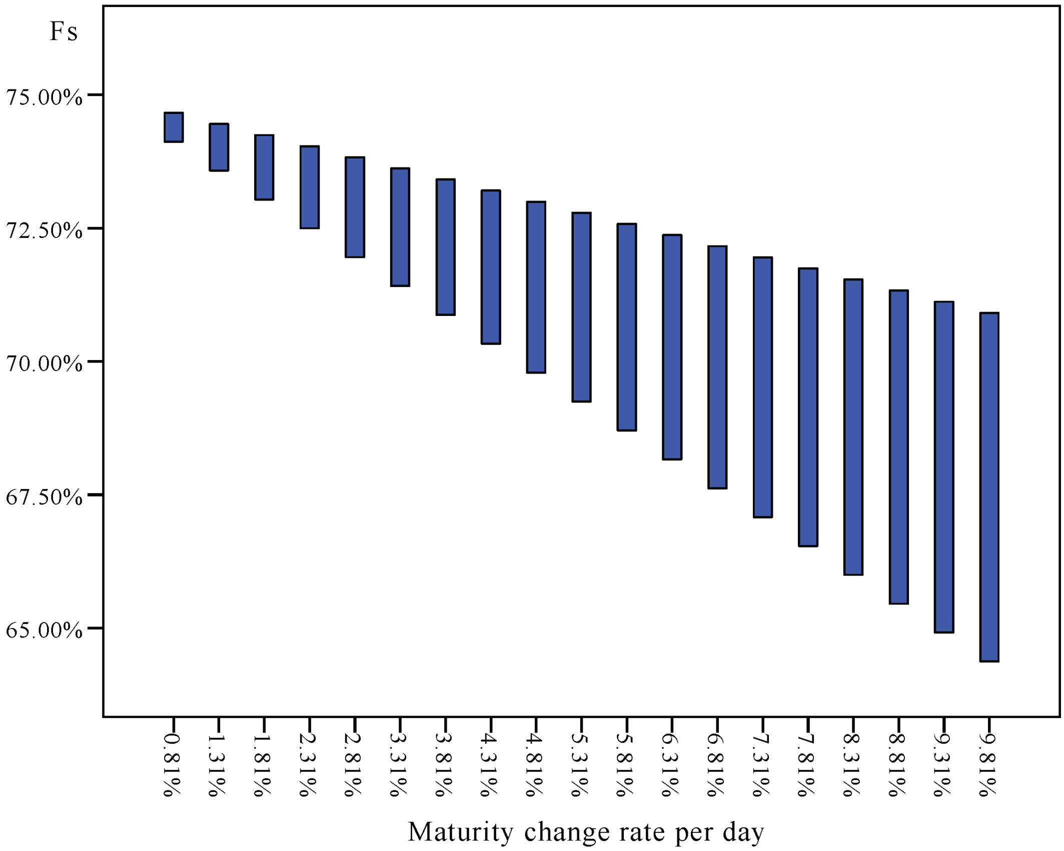

Figure 8. Results of sensitivity analysis

From Figure 8, it can be observed:

1) When average daily change rate of maturity is 2.31%, it takes 9 days from picking to eating, and corresponding maturity interval for fruit farmers to delivery is $[72.5\%, 74.04\%]$. When average daily change rate of maturity is increased to 9.81%, mature time required from picking to reaching edible maturity is only 2.1 days, fruit farmers need to choose fruit with lower maturity when shipping, and maturity range to delivery is $[64.37\%, 70.91\%]$.

2) With the increase of the average daily change rate, maturity range of fresh fruit to delivery gradually decreases. That is to say, the faster fresh fruit matures, the lower maturity for delivery will be in order to prevent fruit from deteriorating during the transportation. For fruits such as strawberries, cherries and mulberries which ripen quickly after picking, farmers should pick fruits with lower maturity and even raw ones for delivery. For fruits that ripen slowly after picking, such as kiwi fruits, mangos and apples, farmers can pick fruits in advance to store or pick fruits with higher maturity for real-time transportation.

4.3. **Results and discussion.** Maturity of fresh fruit received by customers depends on transportation time and change rate of maturity. Based on the analysis and summary of above results, following suggestions are made for all the fruit farmers.

1) Although transportation time with a central warehouse is short, fruit farmers need to pick fruits in advance and store them in the central warehouse for delivery, which increases storage time. Therefore, for transportation process with a central warehouse, fruit farmers can pick fruits with slower maturity changes or lower maturity for shipment. For transportation without a central warehouse: a) if maturity of fruits changes slowly, fruit farmers can mix low maturity fruits with appropriate maturity fruits to accelerate fruits ripening, so when customers receive fruits, they can eat it at any time, or have a few days to storage; b) if maturity of fruits changes rapidly, fruit farmers had better choose the strategy of picking and delivering, and fruits with low maturity should be picked to prevent rot and deterioration.

2) In the decision-making of fruit delivery, fruit farmers should choose appropriate maturity level according to types of fresh fruits. For fruits with low sensitivity to maturity change after picking, fruits with high maturity should be delivered by fruits farmers; for fresh fruits with high sensitivity to maturity, fruits with low maturity should be delivered by fruits farmers to prevent deterioration and reduce losses of fruit farmers.

5. Conclusions.

Under the environment of e-commerce transportation, the change law of maturity directly affects the quality of fresh fruit reaching to consumers. In order to provide fresh fruit with high quality to customers, this study analyzes the maturity change of fruit in the transportation process from the perspective of the characteristics of fruit. In this paper, the existing transportation network in China and fruit maturity are combined to get the range of fruit maturity changes in the transportation process. This study provides decision-making basis for fruit farmers. From the perspective of the inherent characteristics of fruit, the maturity of fruit is introduced into the transportation of fresh fruit to ensure the quality of fresh fruit.

At the same time, the transportation of fresh fruit considering the maturity provides a direction to solve the "first kilometer" problem of fresh agricultural products. Therefore, this study is helpful to reduce the damage rate and transportation cost of fresh fruit, improve customers satisfaction, and promote sales of fresh agricultural products. Of course, there are some shortcomings in this paper, which does not consider impacts of transit links and transportation conditions on maturity change, and also fails to analyze cost. In the future research, we will further deepen the research from these aspects.

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REFERENCES

[1] M. Du and X. Hu, A group-based order batching method for fruit and vegetable's farm-to-door online retail in metropolises of China, *Frontiers in Artificial Intelligence and Applications*, vol.255, pp.11-20, 2013.

[2] W.-I Lee and C.-L. Lee, An innovative information and relationship between service quality, customer value, customer satisfaction, and purchase intention, *International Journal of Innovative Computing, Information and Control*, vol.7, no.7(A), pp.3571-3581, 2011.

[3] L. Zhao, S. Sun and X. Wang, Tracking and traceability system using livestock Iris code in meat supply chain, *International Journal of Innovative Computing, Information and Control*, vol.7, no.5(A), pp.2201-2212, 2011.

[4] Y. Zhang, L. Sun, X. Hu and C. Zhao, Order consolidation for the last-mile split delivery in online retailing, *Transportation Research Part E: Logistics and Transportation Review*, vol.122, pp.309-327, 2019.

[5] P. Amorim, H.-O. Günther and B. Almada-Lobo, Multi-objective integrated production and distribution planning of perishable products, *International Journal of Production Economics*, vol.138, pp.89-101, 2012.

[6] H.-K. Chen, C.-F. Hsueh and M.-S. Chang, Production scheduling and vehicle routing with time windows for perishable food products, *Computers & Operations Research*, vol.36, pp.2311-2319, 2009.

[7] J. Ruan and Y. Shi, Monitoring and assessing fruit freshness in IOT-based e-commerce delivery using scenario analysis and interval number approaches, *Information Sciences*, vol.373, pp.557-570, 2016.

[8] G. T. Le, T. V. Tran, H.-S. Lee and W.-Y. Chung, Long-range batteryless RF sensor for monitoring the freshness of packaged vegetables, *Sensors and Actuators A: Physical*, vol.237, pp.20-28, 2016.

[9] P. Amorim and B. Almada-Lobo, The impact of food perishability issues in the vehicle routing problem, *Computers & Industrial Engineering*, vol.67, pp.223-233, 2014.

[10] O. Ahumada and J. R. Villalobos, Operational model for planning the harvest and distribution of perishable agricultural products, *International Journal of Production Economics*, vol.133, pp.677-687, 2011.

[11] C. Wei, W. Gao, Z. Hu, Y. Yin and S. Pan, Assigning customer-dependent travel time limits to routes in a cold-chain inventory routing problem, *Computers & Industrial Engineering*, vol.133, pp.275-291, 2019.

[12] K. Óskarsdóttir and G. V. Oddsson, Towards a decision support framework for technologies used in cold supply chain traceability, *Journal of Food Engineering*, vol.240, pp.153-159, 2019.

[13] R. D. Raut, B. B. Gardas, V. S. Narwane and B. E. Narkhede, Improvement in the food losses in fruits and vegetable supply chain – A perspective of cold third-party logistics approach, *Operations Research Perspectives*, vol.6, Article ID 100117, 2019.

[14] T. Defraeye, B. Nicolai, W. Kirkman, S. Moore, S. Niekerk, P. Verboven and P. Cronjé, Integral performance evaluation of the fresh-produce cold chain: A case study for ambient loading of citrus in refrigerated containers, *Postharvest Biology and Technology*, vol.112, pp.1-13, 2016.

[15] Y. Sun, Z. Singh, V. Y. Tokala and B. Heather, Harvest maturity stage and cold storage period influence lemon fruit quality, *Scientia Horticulturae*, vol.249, pp.322-328, 2019.

[16] S. Tu, Y. Xue, C. Zheng, Y. Qi, H. Wan and L. Mao, Detection of passion fruits and maturity classification using Red-Green-Blue Depth images, *Biosystems Engineering*, vol.175, pp.156-167, 2018.

[17] A. Hussain, H. B. Pu and D. W. Sun, Innovative nondestructive imaging techniques for ripening and maturity of fruits – A review of recent applications, *Trends in Food Science & Technology*, vol.72, pp.144-152, 2018.

[18] K. Prasad, S. Jacob and M. W. Siddiqui, Fruit maturity, harvesting, and quality standards, in *Preharvest Modulation of Postharvest Fruit and Vegetable Quality*, M. W. Siddiqui (ed.), London, Elsevier, 2018.

[19] L. Liu, H. Wang and S. Xing, Optimization of distribution planning for agricultural products in logistics based on degree of maturity, *Computers and Electronics in Agriculture*, vol.160, pp.1-7, 2019.

[20] S. Sirithon and K. Niwat, Quality, bioactive compounds and antioxidant capacity of selected climacteric fruits with relation to their maturity, *Scientia Horticulturae*, vol.221, pp.33-42, 2019.

[21] S. W. Chen, M. C. Hsu, H. H. Fang, S. H. Tsai and Y. S. Liang, Effect of harvest season, maturity and storage temperature on storability of carambola 'Honglong' fruit, *Scientia Horticulturae*, vol.220, pp.42-51, 2017.

[22] R. Zhang, J. Liu and B. Liu, Pricing decisions and channel coordination of fresh produce supply chain under multi-transportation modes, *ICIC Express Letters*, vol.12, no.1, pp.9-21, 2018.

[23] R. M. Moshiur, M. Moniruzzaman, M. R. Ahmad, B. C. Sarker and M. K. Alam, Maturity stages affect the postharvest quality and shelf-life of fruits of strawbery genotypes growing in subtropical regions, *Journal of the Saudi Society of Agricultural Sciences*, vol.15, pp.28-37, 2016.

[24] Q. Cheng, B. Sun, Z. Liu, Q. Feng and P. Gu, Geometric error compensation method based on Floyd algorithm and product of exponential screw theory, *Proc. of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol.232, no.7, pp.1156-1171, 2018.

[25] B. Chen, L. Pan, C. Chen and G. Jin, Ripeness of kiwifruit and changes of its nutritional components, *Fujian Fruit Tree*, vol.2, pp.12-15, 1994.
[26] W. Guo, W. Li, B. Yang, Z. Zhu, D. Liu and X. Zhu, A novel noninvasive and cost-effective handheld detector on soluble solids content of fruits, *Journal of Food Engineering*, vol.257, pp.1-9, 2019.