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Determinants for Supplier Selection Based on Hybrid Grey Theory: Case Study of the Vietnamese Coffee Industry

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Abstract: Coffee is not merely a refreshing beverage but also invigorates people, provides relaxation, contributes to human health, and fosters closer social connections. Coffee is one of the most widely consumed beverages worldwide and the most traded commercial commodity. Moreover, the rapid development of the Vietnamese coffee industry caused some concerns due to its insufficient performance and the fierce competition within the industry. It is significant to establish an efficient supply network; notwithstanding, supplier selection has always been a challenge for companies. Therefore, this paper employs a hybrid model to determine the supplier selection criteria, a vital factor for a manufacturer under practical operating conditions. Firstly, a combined model of Grey forecasting and the Grey Fourier series is applied to forecast future rainfall and temperature data for six consecutive years. Secondly, based on the criteria, strategies, and buyer requirements, the single-objective linear programming model helps identify the outperformed suppliers. The results found that prices and location change are determinants of supplier selection, and supplier shortage is an enormous barrier for the industry. In this study, these price forecasts allow supply chain management to make informed decisions about inventory levels, transportation routes, and resource allocation to ensure smooth operation and optimize coffee supply chain management.

Keywords: coffee industry; Grey forecasting; Grey Fourier series; supplier selection; single-objective linear programming

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1. Introduction

In recent times, the global supply chain has faced numerous challenges. Trade tensions between the U.S. and China have resulted in stalled goods. As the pandemic subsides, the ongoing tension between Russia and Ukraine escalates transportation costs. The disruption in the global supply chain has led to a sharp increase in food prices, posing a risk of instability in many developing countries, including Vietnam.

Vietnam is located in the tropical belt of the Northern Hemisphere and has the proper climate for growing coffee trees with special flavor. With extensive and widespread cultivation of coffee across the country's land, Vietnam's harvested coffee area has expanded from 15,000 to nearly 640,000 hectares over the last three decades [1]. In the year of 2019, this industry produced approximately 1.6 million tons of green beans, which contributed to an export value of approximately U.S. $2.85 billion, accounting for about 3% of the national GDP. In recent years, the industry has been the world's second-largest exporter of coffee, after Brazil. The coffee industry has been one of the spearhead economic sectors in Vietnam, mainly produces Robusta coffee, accounts for 60% of Robusta worldwide, and is regarded as having the highest levels of productivity in the globe at the lowest price [2].

Coffee trees commonly grow in tropical regions where abundant rainfall, warm temperatures, and no frost are [3,4]. Franca et al. (2005) and Silva (2005) believed that factors such as the climate, soil, rainfall, and a suitable system of cultivation and irrigation in certain localities must be regarded as vital values for good coffee tastes [5,6]. The Arabica coffee is a perennial plant and evergreen in nature, the best coffees are grown at altitudes above 1000 m where the annual rainfall remains below 1500 mm with favorable environmental quality such as rainfall, altitude, latitude, and longitude [7].

In North Vietnam, the climate is strongly influenced by northeastern winds, which, combined with heavy rainfall and cold weather, are not conducive to the growth and development of coffee [8,9]. Notwithstanding, coffee from this area has a distinctive taste, which is highly appreciated by customers worldwide similar to coffee from Sao Paulo, Brazil [10]. In particular, coffee trees in Son La and Dien Bien provinces are grown at relatively high latitudes. It is not needed for frequent irrigation, but their coffee has a rigorous quality standard and is considered specialty coffee [11]. The hot climate of middle Vietnam, Quang Tri is well-suited for Arabica coffee plantation with a deep aroma [12]. Dak Mil rural district, located in the central highlands region of Vietnam, close to the equator, the characteristic of the hot wet climate and is suitable for Robusta coffee trees [13,14]. This area has up to 19,000 hectares of coffee planting trees, accounting for one-third of the coffee output of the whole Dak Nong province [15]. The coffee trees can be grown in various soils, such as reddish-brown soil, golden-brown soil, and gray soil [16,17]. Compared to all soil types, Bazan red soil can prolong the life cycle of coffee trees, and it has a significant effect on the taste and color of coffee [18,19].

It is important to investigate the supply network of unprocessed coffee products from the three largest cities located from the north to the south of Vietnam, which are Hanoi capital, Da Nang, and Ho Chi Minh City. Figure 1 shows the general scenario of the Vietnamese agriculture industry and illustrates the connection between the government, agricultural companies, and farmers, which is the fundamental nature of the product lifecycle from coffee bean growers to end customers.

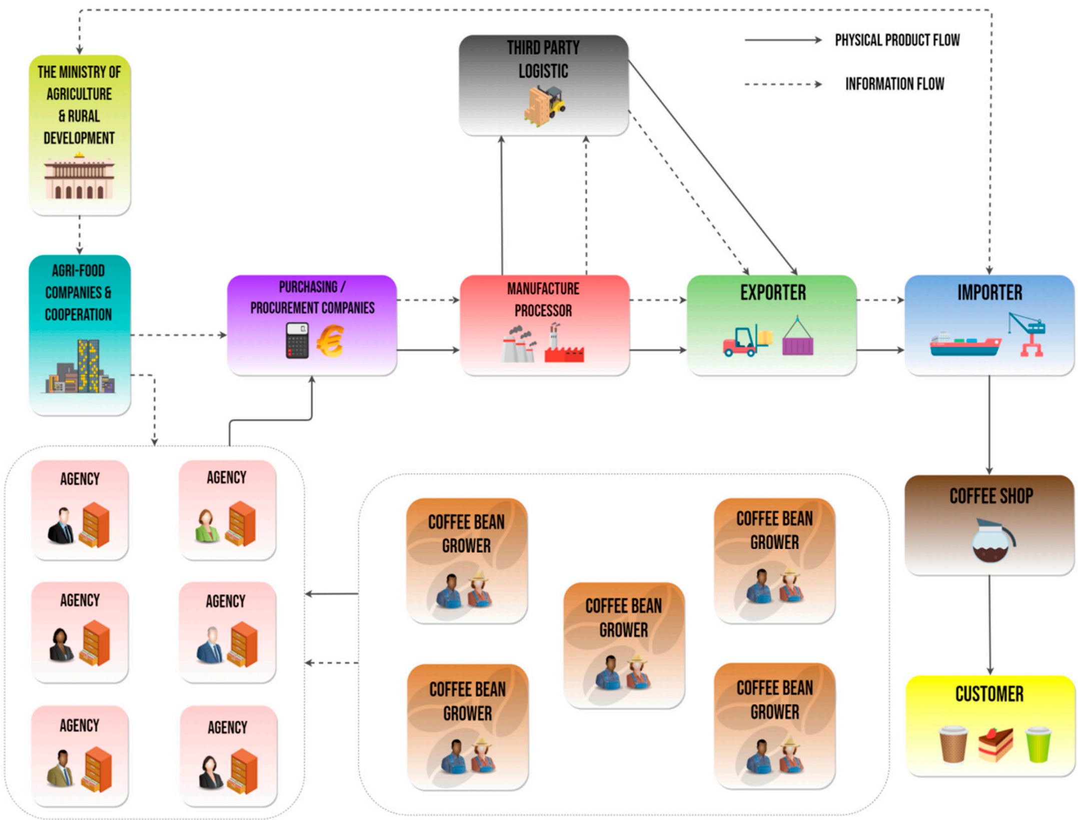

Figure 1. A framework of Vietnamese coffee supply network.

Currently, Vietnam has about 150 coffee-exporting agencies, and these companies commonly buy green bean coffee from self-organizing logistics systems and purchasing agents [20]. The agricultural export crop contract is signed by the government to provide an outline of the food supply chain system from multiple angles and then inform the food companies and cooperative farms in Vietnam. The coffee bean growers, the agents, and the exporters formed the bottlenecks of Vietnamese coffee supply networks. The farmers harvest and dry green coffee beans before delivering them to the agencies. The agents negotiate with the larger ones or directly contact the manufacturer processor. The intermediate coffee bean suppliers select the types of coffee beans and deliver them to the manufacturers to produce the final products on a large scale. With the cooperation of its special network, the processing manufacturers order vast quantities from the local agents, create a feasible schedule to avoid late deliveries, and then check the export allotment quota for the crop. All procedures for concluding contracts for supplier selection must be executed carefully in terms of costs and regulations. Third-party logistic providers transfer the product to the buyers, who are importers and wholesalers, and the importer countries. Companies used to purchase the products directly from their long-term relations with the coffee growers or agencies; consequently, this led to restrictions on providing high-quality products and created an inefficient supply network within their industry.

According to Scherr et al. (2015) despite its large scale and diversity of coffee commodities across the nation, the industry is being threatened by very weak governance involving an amorphous combination of institutions, agencies, and farmers [21]. In addition, Keshky et al. (2020) coffee value chain is a vulnerable industry facing difficulties from external shocks such as natural disasters and trade protectionism, which may cause disruption of the global value chain [22]. Any inaccuracy in the supplier selection process can lead to substandard performance. Meanwhile, successful supplier selection will benefit the long-term development of the Vietnamese coffee industry by reducing operational and environmental costs and improving product quality.

Lin and Wu (2011) proved that the procurement activities of purchasing firms can support decision-making by identifying potential alternatives and selecting the best products in favor of the buyer's objectives [23]. Hammani et al. (2014) Supplier selection for the success of companies and industries is crucial for competitiveness in a fierce market-competition environment [24]. The selection of suppliers is crucial in developing a reliable supply chain and is devoted to effectively contributing to the mutual co-business development profits [24]. Global sourcing often aims to exploit the performance in the supply of products; it is also a prevailing trend among companies specializing in production-oriented agribusiness seeking new sources for competitive advantage [1].

Global sourcing often aims to exploit the performance of the supply of products. It is also a prevailing trend among companies specializing in production-oriented agribusiness seeking new sources for competitive advantage [25]. Manufacturers might optimize their value chain production and associated processes by adopting and selecting coffee bean vendors. Selecting suppliers aims to significantly optimize prices due to the effective use of energy and resources with less cost wastage.

Kittichotsatsawat et al. (2021) found that significant coffee problems were identified, such as high cultivation costs, a lack of standards to produce high-quality coffee, and unplanned incoming material (coffee cherries) that led to continuous losses and disappearing customer confidence. Vietnam also has the same problem as Thailand; however, transportation cost is the most important factor in determining the price and selecting the vendor cost in coffee manufacturing [26]. The coffee bean-growing regions in Vietnam are mainly dependent on collectors and traders. Engaging in the agriculture value chain helps ensure that the participants share rights and responsibilities, regulate market supply and demand, and trace the origin of products. It meets agricultural development needs, enhances production efficiency, and increases income for farmers and businesses. An effective and optimized supplier selection process is of pivotal importance for manufacturing organizations and all organizations in the age of the industrial revolution. Choosing the right supplier can help reduce purchasing risks, maximize value, and increase total quality management production.

This research aims to help manufacturers optimize their value chain's production and associated processes by selecting coffee bean vendors to reduce supply chain disruption. It proposes the selection criteria for optimizing supplier selection, for which previous research has not finished incorporating environmental factors into the conventional supplier selection model. The agricultural industry is inherently vulnerable to environmental challenges. The data was used in agrarian management of weather and climate change to predict the yield of croppers. Moreover, this study provides an empirical initiative based on a mixed model of grey forecasting in conjunction with the Grey Fourier series, a powerful method for accurately anticipating future values for this industry. In addition, a mathematical analysis based on binary linear programming is utilized to identify the necessary criteria for choosing desirable suppliers for coffee manufacturing. Overall, this study is intended to enhance the supplier domestic network, increase competitive ability, and help coffee growers improve productivity in cultivation.

2. Literature Review

The Vietnamese coffee industry has been experiencing significant growth and expansion in recent years. This growth has led to an increased demand for high-quality coffee beans, requiring the industry to have efficient supplier selection and order allocation processes (Siregar et al., 2019). One of the critical factors affecting the quality and price of coffee beans is the level of rainfall and temperature [27]. According to Dang et al. (2022), there have been increasing discussions in supplier selection research on enhancing supplier capabilities toward green and sustainable practices [28]. The supply networks and the competitiveness of a particular industry depend on supplier selection capacity to find solutions to address the urgent economic, political, and war crises. Agarwal and Vijayvargy (2011) emphasized that higher cooperation and coordination among the partners of the supply chain is a key issue, which requires strategies suitable for system optimal performance [29]. The selection of qualified suppliers must match the adequate evaluation criteria to ensure the right supplier is chosen. In other words, Li et al. (2020) once the qualified supplier becomes a critical cell of a well-managed and established supply network, the linkage between the buyer and supplier will significantly affect the well-run supply chain. In agribusiness supply chains, supplier selection behavior can be regarded as industrial buying behavior because of the need to purchase inputs from various sources [30]. Such organizational buying behavior is a complex decision-making and communication process involving numerous internal and external participants in the purchasing organization [31]. Suppliers are not the greatest assets in an organization, but poor choices can make them the most significant liability. Liao (2012) suggested that selecting the right agricultural product suppliers significantly decreases purchasing costs, improves competitive advantage, and enhances customer satisfaction [32]. Liu (2013) defined smaller independent food retailers with less negotiating power as having selection criteria and technological specifications for their suppliers. They tend to work with existing vendors to develop and co-create technological compatibility and specifications [33]. Thus, in today's rapidly changing world, the significance of accurate weather forecasts and vendor cost estimation in supply chain management cannot be overstated. Precise weather forecasts provide vital information for supply chain managers to anticipate and respond to potential risks and threats. These forecasts allow them to make informed decisions about inventory levels, transportation routes, and resource allocation to ensure the smooth operation of the supply chain. Additionally, accurate vendor cost estimation helps supply chain managers select the best vendors based on price uncertainty in the future. This allows them to optimize costs and maintain competitiveness in the market. Furthermore, accurate weather forecasts and vendor cost estimation play a crucial role in preserving the resilience and competitiveness of the coffee supply chain.

Grey system theory was initially introduced by Professor Deng based on mathematical analysis in 1982. The model has been famous among worldwide researchers due to its outperformed ability to solve unknown problems and deal with uncertain values [33].

Peng mentions with a few parameters required to apply the Grey model, it has been applied to many industries by providing various available solutions [34]. Building upon Deng's model, Odan et al., (2012) proved that linear statistical forecasting methods are widely used because they are easy to implement and fully understand the indicators [35]. However, in the real world, data have varying degrees of nonlinearity, which may not be adequately handled by linear applications. Many nonlinear methods were proposed in applied economic cases to improve forecasting performance. According to Hsu et al. (2009) obtained good performance on the various prediction applications using the Fourier series to refine the residual state transition matrices [36]. Wang and Phan (2015) illustrated the empirical idea that using Fourier series techniques can filter out high-frequency terms, which are considered to be noise, but achieve better performance [37]. González et al., (2008) and Romera and Seifert (2009) agreed that some data from the series would be used to fit a Fourier series made up of the peak frequencies of the spectrum plot of the fluctuation series [38,39]. Rahmawati and Salimi (2022) decided on the local, freshly roasted coffee for the domestic market [40]. However, this research didn't have a different delivery location. This Fourier series is used to forecast fluctuations that are different from those used for fitting. Demand forecasting is calculated by adding the trend prediction and is used to predict fluctuations in coffee vendors. The underlying reason for this approach is examining supplier selection from the manufacturers' perspective and an increasingly integrated and more complex production-distribution system.

3. Methodology

Formerly, companies made supplier selection decisions based on competitive prices. Studies in the field of supplier selection rose sharply after the 1960s. Therefore, the determinants of the selection criteria became significant issues that needed to be addressed. Supplier selection is a complex decision-making problem that should include both quantitative and qualitative criteria needed for suppliers' performance effectively. Some researchers have agreed that a combination of factors should fit the technical requirements and the company's targets.

A new approach based on the Grey model is employed to foresee future values. Grey model forecasting G.M. (1,N) is extensively used in many applications. The discrete Grey models are a class of new models initially developed that are characterized by poor information and a lack of information. The fields covered by Grey theory include systems analysis, data processing, modeling, prediction, decision-making, and control. Thus, the G.M. (1,1) is one of the most frequently models used in a series of Grey forecasting [33]. The paper adopted Curzi (2015) to describe the procedure in which price, rainfall, and temperature indicators from standard disaggregate trade data are used to anticipate future information [41]. Based on previous studies, Zeithaml (1988) designed a way to test the general wisdom that price and quality are positively related [42].

Based on the research of Amid et al., (2009), the study develops the single-objective linear programming model, which is a useful approach for supplier selection in the agriculture industry [43]. To specify the weight or goal priorities towards the best selection, a mathematics analysis of single-objective linear programming was applied to solve these problems, which is an outperformed application appropriate for the purpose of this study. The findings contribute to the existing literature by comparing analytical statistics and building the equation in order to obtain the average coffee price. The single linear programming model is applied to an actual case study for supplier selection in the coffee industry, where companies try to reduce manufacturing costs. Competitive price is regarded as one of the most important factors affecting consumers' buying decisions. Thus, we assumed a temperature mean of T_1 and a rainfall mean of T_2 to assess the impact of factors affecting the quality of the coffee bean and then calculate the coffee price in the Vietnamese market. P means the average price of the Vietnamese coffee bean. This section describes the procedure that infers, using T_1 and T_2, information from standard disaggregate trade data based on the statistics formulation:

$$P = \beta_0 + \beta_1 T_1 + \beta_2 \ln(T_2) \quad (1)$$

where

$$T_2 = \ln(T_2) \quad (2)$$

3.1. Grey Forecasting

In this case, data were collected over six consecutive years, from 2017 to 2022. The authors applied the Grey model in this study to forecast the effect of price on coffee in the future. The Grey system theory, developed by Deng in 1982, is an important methodology that focuses on the study of problems involving small samples and poor information.

Theorem 1: *Let $X^{(0)}$, $X^{(1)}$, and $Z^{(1)}$ be the same as above except that $X^{(0)}$ is non-negative. If $\hat{a} = (a, b)^T$ is a parameter sequence and:*

$$Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, \quad B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & 1 \\ -z^{(1)}(n) & 1 \end{bmatrix}, \quad (3)$$

The least squares estimate sequence of the G.M. (1,1) model Equation (2) satisfies $\hat{a} = \left(B^T B\right)^{-1} B^T Y$. Continuing all the notations from Theorem 1, if $[a, b]^T = \left(B^T B\right)^{-1} B^T Y$, then $\frac{dx^{(1)}}{dt} + ax^{(1)} = b$ is a whitenization equation of the G.M. (1,1) model in Equation (3). The time response sequence of the G.M. (1,1) model in Equation (5) is given below.

$$\hat{X}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-ak} + \frac{b}{a}, k = 1, 2, \ldots, \quad (4)$$

The parameters $(-a)$ and b of the GM (1,1) model are referred to as the development coefficient and Grey action quantity, respectively. The former reflects the development states of $\hat{x}^{(1)}$ and $\hat{x}^{(0)}$. In general, the variables that act upon the system of interest should be external or pre-defined. Because G.M. (1,1) is a model constructed from a single sequence, it uses only the behavioral sequence (referred to as output sequence or background values) of the system without considering any externally acting sequences (referred to as input sequences or driving quantities). The Grey action quantity in the G.M. (1,1) model is a value derived from the background value. It reflects changes contained in the data, and Its exact intention is Grey. For this quantity, rainfall and temperature realize the extension of the relevant intention. Its existence distinguishes Grey systems modeling from general modeling. It is also an important test to separate the thoughts of Grey systems and those of Grey boxes.

3.2. Grey Fourier Series

González et al. (2010) [38] separated the thoughts of Fourier series systems and those of forecasting boxes, which is also an important test.

Theorem 2: *Let $X^{(0)}$be the original series of m entries, and v is the predicted series obtained from NGBM (1,1). Based on the predicted series v, a residual series named ε is defined as follows:*

$$\varepsilon = \{e(k)\}, \quad k = 2,\ 3,\ \ldots\ m$$

where

$$e(k) = x(k) - v(k) \quad k = 2,\ 3,\ \ldots\ m \quad (5)$$

According to the definition of the Fourier series, the residual sequence of NGBM (1,1), can be approximately expressed as follows:

$$\hat{\varepsilon}(k) = \frac{1}{2}a_{(0)} + \sum_{i-1}^{z}\left[\left[a_i\cos\left(\frac{2\pi i}{m-1}(k)\right)\right] + b_i\sin\left(\frac{2\pi i}{m-1}(k)\right)\right] \quad k = 1,2,3,\ldots m \tag{6}$$

where

$$Z = \frac{(m-1)}{2} - 1 \tag{7}$$

is called the minimum deployment frequency of the Fourier series and Z only be taken integer number.

Therefore, the residual series is rewritten as follows:

$$\varepsilon = PC \tag{8}$$

where

$$P = \begin{bmatrix} \frac{1}{2}\cos\left(\frac{2\pi i\times 1}{m-1}\times 2\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 2\right) & \ldots & \frac{1}{2}\cos\left(\frac{2\pi i\times Z}{m-1}\times 2\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times 2\right) \\ \frac{1}{2}\cos\left(\frac{2\pi i\times 1}{m-1}\times 3\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 3\right) & \ldots & \frac{1}{2}\cos\left(\frac{2\pi i\times Z}{m-1}\times 3\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times 3\right) \\ \vdots & \ldots & \vdots \\ \frac{1}{2}\cos\left(\frac{2\pi i\times 1}{m-1}\times m\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 3\right) & \ldots & \frac{1}{2}\cos\left(\frac{2\pi i\times Z}{m-1}\times m\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times m\right) \end{bmatrix} \tag{9}$$

$$C = [a_0, a_1, b_1, a_2, b_2, \ldots, a_z, b_z]^T \tag{10}$$

The parameters $a_0, a_1, b_1, a_2, b_2, \ldots, a_z, b_z$ are obtained by using the ordinary least squares (O.L.S.) method whose results are in the following equation:

$$C = \left(P^TP\right)^{-1}P^T\varepsilon^T \tag{11}$$

Once the parameters are calculated, the modified residual series is then achieved based on the following expression:

$$\hat{\varepsilon}(k) = \frac{1}{2}a_0 + \sum_{i=1}^{z}\left[a_i\cos\left(\frac{2\pi i}{m-1}(k)\right) + b_i\sin\left(\frac{2\pi i}{m-1}(k)\right)\right] \tag{12}$$

From the predicted series v, and $\hat{\varepsilon}$ the Fourier modified series $\hat{v}$ of series v is determined by the following:

$$\hat{v} = \{\hat{v}_1, \hat{v}_2, \hat{v}_3, \ldots, \hat{v}_k, \ldots, \hat{v}_m\}$$

where

$$\hat{v} = \begin{cases} \hat{v}_1 = v_1 \\ \hat{v}_k = v_k + \hat{\varepsilon}_k \end{cases} \quad k = 2,\ 3,\ \ldots,\ k \tag{13}$$

There are some common approaches for evaluating the performance of the volatility model for forecasting. This study adopted two criteria to evaluate the forecasting model of the coffee price. Model characteristics include periodicity, randomness, and tendency. According to Liu et al. (2023), to obtain the tendency of the series and the context of the development of natural disasters, this study is not only used to improve the background value using integration but also to increase the accuracy by correcting the model's periodical errors [44]. The mean absolute percentage error (MAPE) is defined as follows:

$$MAPE = \frac{1}{n}\sum_{k=2}^{n}\left|\frac{x^{(0)}{}_{(k)} - \hat{x^{(0)}}{}_{(k)}}{x^{(0)}{}_{(k)}}\right| \times 100\% \tag{14}$$

where $x^{(0)}(k)$: the actual value in time period k, and $\hat{x}^{(0)}(k)$: the forecast value in the time period.

The grade of MAPE is divided into four levels shown in Table 1.

Table 1. The MAPE grade level [22].

MAPE	**≤10%**	**10–20%**	**20–50%**	**>50%**
Grade levels	Excellent	Good	Qualified	Unqualified

We ensure no space for errors during the forecasting calculation because forecasting accuracy is important to solve mathematical concerns for future values with incomplete information. Therefore, in this paper, the MAPE is employed to measure the accuracy of the method for constructing fitted time series values. When MAPE values are small, the predicted values are close to the actual values.

3.3. Single-Objective Linear Programming Model

Decision variables are as follows:

Kij Quantity weight total purchase of agency i supplied by supplier j (in Ton)
Qij 0–1 variable determined by whether agency i is provided by supplier j (=1 if supplied)

Parameters:

Pij Price of supplier j
Ci Capacity of supplier j
tij Transportation cost agency i from supplier j
Di Total demand for agency i
qij Percent of defective parts for agency i supplied by supplier j
mij Minimum order quantity for agency i required by supplier j
M A large positive number

Single-objective Linear programming supplier selection with functions is based on a formulation for which Z is a minimization objective whereby Z represents the total transportation cost of the product.

$$\text{Min } Z = \sum_i \sum_j p_{ij} K_{ij} + \sum_i \sum_j t_{ij} K_{ij} \tag{15}$$

Subject to:

$$\sum_{i=1}^{3} XK_{ij} \le C_j \quad \forall j \tag{16}$$

$$\sum_{j=1}^{5} K_{ij} \ge D_i \; \forall i \tag{17}$$

$$K_{ij} \ge m_{ij} K_{ij} \quad \forall i, j \tag{18}$$

$$K_{ij} \le M K_{ij} \; \forall i, j \tag{19}$$

$$K_{ij} \ge 0 \quad \forall i, j \tag{20}$$

$$Q_{ij} \in \{1, 0\} \; \forall i, j \tag{21}$$

Constraint set (15) serves as the capacity constraint for each vendor, and set (16) serves as the overall capacity restriction. Constraint set (17) enforces the fulfillment of the demanded quantity for each part. Constraint set (18) specifies the minimum order quantity for all vendors. The constraint set (19) prevents conflict between the decision variables. Constraint set (20) preserves the non-negativity, and set (21) imposes the integrality on the decision variables.

4. Results and Analysis

This paper assumes that the proper and qualified sellers must meet all buyers' requirements. The selected criteria are the factors of temperature and rainfall. Each criterion will contribute to the appropriate sourcing evaluation in the model's objective function for the industrial food chain. This is in conjunction with some criteria used to form the model constraints so that the feasible region can be located; in this real case, these are rainfall and temperature. Thus, we assumed that temperature means X_1 and rainfall means X_2 to assess the impact of factors affecting the quality of coffee beans and then calculate the coffee price in the Vietnamese market. P is the average price of Vietnamese coffee beans. The data on temperature, rainfall, and price for coffee from 2017 to 2022 undertaken from five meteorological regions in Vietnam are calculated by the authors. Based on the data from the Vietnam General Statistics Office [45], the SPSS 21.0 software was applied to identify the unstandardized coefficients β_0, β_1, β_2. This β_0, β_1, β_2 index help identify the target price, which is the elasticity of substitution. After running the software regression model, values of prices are obtained as shown in Table 2.

Table 2. The coefficients of the regression model for price forecasting.

Unstandardized Coefficients	Value
β_0	832.217
β_1	34.022
β_2	68.472

Source: Author's calculation.

Based on indicators of rainfall and temperature collected through five different meteorological regions from the regression model, the study develops a prediction model for the value of rainfall and temperature, which is used to calculate the future prices for the next section. All data are computed in the formulation:

4.1. Grey Forecasting

The sequence of raw data $X^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), x^{(0)}(4), x^{(0)}(5), x^{(0)}(6)\right) =$ (21.11, 21.61, 21.85, 21.49, 22.6, 22.35) simulate this sequence $X^{(0)}$ using the following three G.M. (1,1) models and comparing the accuracy of the simulation:

From Equation (2) $x^{(0)}(k) + az^{(1)}(k) = b$, compute the accumulation generation of $X^{(0)}$ as follows:

$$X^{(1)} = \left(x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), x^{(1)}(4), x^{(1)}(5)\right) = (21.11,\ 42.72,\ 64.57,\ 86.06,\ 109,\ 131.01)$$

We check the quasi-smoothness from $\sigma^{(1)}(k) = \frac{x^{(0)}(k)}{x^{(1)}(k-1)}$. It follows that $\sigma^{(1)}(2) = 0.49$, $\sigma^{(1)}(3) = 0.33$, $\sigma^{(1)}(4) = 0.25$, and $\sigma^{(1)}(5) = 0.2$, $\sigma^{(1)}(6) = 0.17$. Therefore, $k > 5$, $\sigma^{(1)}(k) \in 0.1;1\Big]$ with $\sigma = 0.9$, that is, the law of quasi-exponentially and the condition of quasi-smoothness is stratified. Thus, we can establish a G.M. (1,1) model for $X^{(1)}$. Using the adjacent neighbors of sequence, let $Z^{(1)} = \left(z^{(1)}(1), z^{(1)}(2), \ldots, z^{(1)}(n)\right)$ be the sequence generated from $X^{(1)}$ by the adjacent neighbor means sequence.

$$Z^{(1)} = \left(x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), x^{(1)}(4), x^{(1)}(5)\right) = (32.91,\ 54.64,\ 76.31,\ 110,\ 132.01)$$

In addition, matrix B and constant vector Y_N are accumulated as follows:

$$B = \begin{bmatrix} -32.92 & 1 \\ -54.64. & 1 \\ -76.32 & 1 \\ -98.36 & 1 \\ -120.83 & 1 \end{bmatrix} \quad Y_N = \begin{bmatrix} 21.61 \\ 21.85 \\ 21.49 \\ 22.6 \\ 22.35 \end{bmatrix}$$

Using the least squares estimation, we obtain the sequence of parameters $\hat{a} = [a, b]^T$ as follows $\hat{a} = \left(B^T B\right)^{-1} B^T Y = \begin{bmatrix} -0.0102 \\ 21.201 \end{bmatrix}$. We establish the following model $\frac{dx^{(1)}}{dt} - 0.0102x^{(1)} = 21.201$ and its time response form $\hat{x}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-a(k)} + \frac{b}{a} = -21.21e^{-0.0102} + 0.00048$. Substituting different values of k into the equation: $k = 1X^{(1)}(1) = 21.11$.

Compute the simulated values of $X^{(0)}$ using the original series according to the accumulated generating operation by using $\hat{x}^{(0)}(k+1) = \alpha^{(1)}\hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k)$.

4.2. Grey Fourier Series

Let x be the original series of m entries and v is the predicted series (1,1). Base on the predicted series v, a residual series named ε is defined as:

$$e(k) = \{-1.0236, -1.9879, -2.9386, -4.0563, -4.7969\} \tag{22}$$

According to the definition of the Fourier Series, the residual sequence of NGBM (1,1), can be approximately expressed as follows:

$$\hat{\varepsilon}(k) = -0.5065 + \sum_{i=1}^{z}\left[-1.0413cos\left(\frac{2\pi i}{m-1}(k)\right) - 0.1308sin\left(\frac{2\pi i}{m-1}(k)\right)\right]$$

where

$$Z = \frac{(m-1)}{2} - 1$$

is called the minimum deployment frequency of Fourier series and Z only be taken integer number.

Therefore, residual series is rewritten as follows:

$$\varepsilon = PC$$

$$P = \begin{bmatrix} \frac{1}{2}cos\left(\frac{2\pi i\times 1}{m-1}\times 2\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 2\right) & \ldots & \frac{1}{2}cos\left(\frac{2\pi i\times Z}{m-1}\times 2\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times 2\right) \\ \frac{1}{2}cos\left(\frac{2\pi i\times 1}{m-1}\times 3\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 3\right) & \ldots & \frac{1}{2}cos\left(\frac{2\pi i\times Z}{m-1}\times 3\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times 3\right) \\ \frac{1}{2}cos\left(\frac{2\pi i\times 1}{m-1}\times 4\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 4\right) & \ldots & \frac{1}{2}cos\left(\frac{2\pi i\times Z}{m-1}\times 4\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times 4\right) \\ \frac{1}{2}cos\left(\frac{2\pi i\times 1}{m-1}\times 5\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 5\right) & \ldots & \frac{1}{2}cos\left(\frac{2\pi i\times Z}{m-1}\times 5\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times 5\right) \\ \frac{1}{2}cos\left(\frac{2\pi i\times 1}{m-1}\times 6\right)\sin\left(\frac{2\pi i\times 1}{m-1}\times 6\right) & \ldots & \frac{1}{2}cos\left(\frac{2\pi i\times Z}{m-1}\times 6\right)\sin\left(\frac{2\pi i\times Z}{m-1}\times 6\right) \end{bmatrix}$$

The parameters $a_0,\ a_1, b_1, a_2, b_2,\ \ldots, a_z, b_z$ are obtained by using the ordinary least squares (O.L.S.) method whose results are in the following equation:

$$C = \left(P^T P\right)^{-1} P^T \varepsilon^T$$

Once the parameters are calculated, the modified residual series as than achieved based on the following expression:

$$\hat{\varepsilon}(k) = -0.5065 + \sum_{i=1}^{z}\left[-1.0413cos\left(\frac{2\pi i}{m-1}(k)\right) - 0.1308sin\left(\frac{2\pi i}{m-1}(k)\right)\right]$$

From the predicted series v, and $\hat{\varepsilon}$, the Fourier modified series $\hat{v}$ of series v is determined. Where

$$\hat{v} = \begin{cases} \hat{v}_1 = 21.11 \\ \hat{v}_2 = 21.5351 \end{cases}$$

- Based on the actual results by applying the Grey forecasting and Grey Fourier series, it was found that the Grey Fourier series has a higher frequency spectra uncertainty than

Grey forecasting. Hence, this study adapts the Grey Fourier series for estimating the uncertain quantitative level of rainfall and temperature data for six consecutive years.

- By the same calculation and procedures, based on the actual data from 2017 to 2022, this study obtained all the forecasted values of all Vietnamese coffee companies from 2023 to 2028, which are shown in Table 3. The forecasting of rainfall and temperature from 2023 to 2028 and Figure 2 comparing the results of Grey forecasting model and Fourier series.

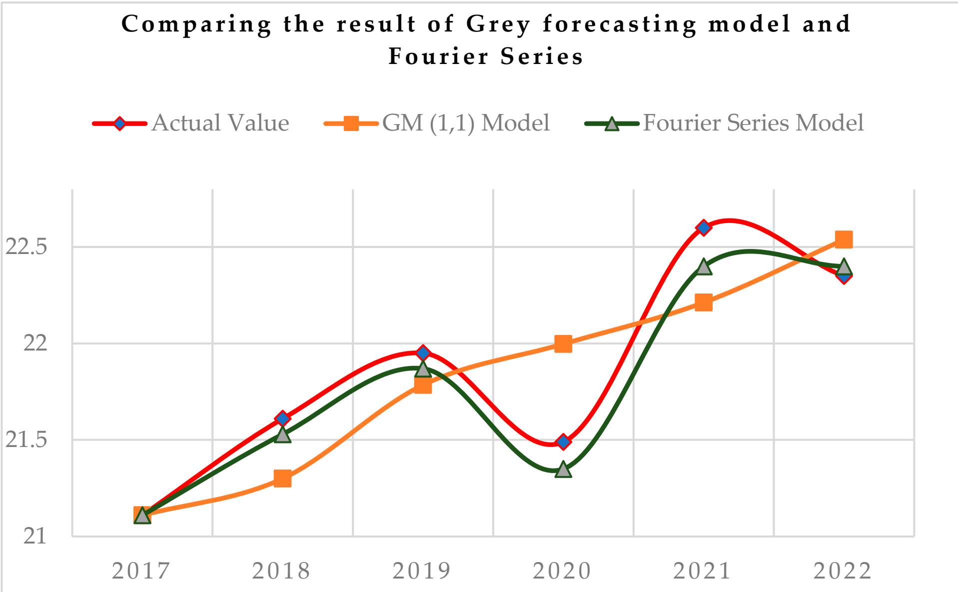

Figure 2. Comparing the result of the Grey forecasting model and Fourier series.

Table 3. The forecasting of rainfall and temperature from 2022 to 2027.

Year	S1		S2		S3		S4		S5	
	X1	X2	X1	X2	X1	X2	X1	X2	X1	X2
2023	22.89	7.48	20.85	7.74	20.39	7.41	23.20	7.34	24.61	7.57
2024	23.12	7.51	20.59	7.75	20.40	7.40	23.42	7.34	24.59	7.54
2025	23.36	7.55	20.33	7.76	20.41	7.39	23.65	7.33	24.58	7.50
2026	23.60	7.58	20.08	7.77	20.43	7.38	23.87	7.32	24.56	7.47
2027	23.84	7.62	19.83	7.78	20.44	7.37	24.10	7.32	24.54	7.44
2028	24.08	7.65	19.58	7.79	20.45	7.36	24.33	7.31	24.52	7.40

Source: Author's calculation.

- From the results of the forecasting, the authors found the coffee price for each supplier in the year 2023, which will help the manufacturer obtain various overviews of different coffee prices. In order to ensure there is no space for errors or mistakes during the forecasting calculation, MAPE is applied to measure the accuracy of the prediction model. The results are shown in Table 4 below.

Table 4. The MAPE for each supplier.

	S1		S2		S3		S4		S5	
Average MAPE	X1	X2	X1	X2	X1	X2	X1	X2	X1	X2
	0.861	0.600	1.669	0.540	0.301	0.359	0.856	0.203	1.006	0.479
	Average = 0.6874									

Source: Author's calculation.

Subsequently, MAPE is employed to measure the accuracy of the average Vietnamese coffee using the price for the forecasting year 2023. Table 5 shows that all MAPEs are smaller than 10%, which is considered as a good performance.

Table 5. The accuracy of the Grey Fourier series forecasting.

Average MAPEPrice's 2022	S1	S2	S3	S4	S5
	4.372	0.265	0.853	4.139	6.059
			Average = 3.14		

Source: Author's calculation.

As the results show in Table 5, the average MAPE of five growers in the year 2023 is 3.14% compared with the average real price, which is regarded as an excellent calculation. It strongly confirms that the Fourier series is highly accurate. Therefore, the study moves to the next stages of the calculation for the average price in 2023 using the Linear program: $P = \beta_0 + \beta_1 T_1 + \beta_2 \ln(T_2)$.

As the results of the statistical methods presented in Table 6, the study obtains a comprehensive estimation of the price. Once the estimation is obtained, the model of Single-objective Linear programming is proposed to select the proper suppliers.

Table 6. The average coffee price forecasting for 2023.

Price	**2023**
S1	2144
S2	2055
S3	2033
S4	2139
S5	2182

Source: Author's calculation.

4.3. Single-Objective Linear Programming Model

To judge the applicability of the single-objective linear programming model, actual data collected from a Vietnamese coffee manufacturer is used for this research.

The manufacturing procurement practices of the components required to produce a specific type of coffee have been purchased from several agencies. In this research, Arabica coffee is supplied by five potential vendors to five agents. It assumes that the expected demand for each agency is 2000, 1600, and 2900; then the minimum order quantities imposed by each supplier should be 150, 200, 150, 200, and 250. In this situation, the coffee bean price in the year 2022 was forecasted by the Grey model and given in Table 7.

Table 7. Transportation cost for each grower.

Supplier i / **Growers j**	**Transportation Cost USD/Ton to Supplier 1**	**Transportation Cost USD/Ton to Supplier 2**	**Transportation Cost USD/Ton to Supplier 3**
1	142	163	281.6
2	142	163	281.6
3	186	135	220
4	210	164	220
5	210	164	158.4

Source: Author's calculation.

In this case study, for the optimal transfer of coffee beans from each grower to suppliers, three manufacturers from large cities collected and processed into the final products before delivering them to customers. Various transportation costs are incurred and shown in Table 7.

The results illustrated in Table 8 pointed out that the objective of minimum transportation cost is 14,805,470 USD for 6500 tons of coffee beans from five growers. In order to minimize cost and obtain the best choice, supplier 1 will buy 650 tons of coffee beans from grower 1; 1000 tons of coffee beans from grower 2; and 350 tons of coffee beans from grower 4. Supplier 2 will buy 250 tons of coffee beans from grower 3; 950 tons of coffee beans from grower 4; and 400 tons of coffee beans from grower 5. Then, supplier 3 will buy 700 tons of coffee beans from grower 1; an amount of 200 tons of coffee beans from grower 2; an amount of 1000 tons of coffee beans from grower 3; and 1000 tons of coffee beans from grower 5. In other words, the decision-makers prefer a supplier with a targeting price, optimal transport, and grower capacity. This paper indicates that price and location change are determinative factors for supplier selection. The empirical model of supplier selection is accurate and powerful for manufacturers to reduce business and transportation costs. In addition, it also helps to maintain the quality of products, provide targeting strategies for firms, and enhance the performance of the entire industry.

Table 8. The results of the supplier selection model.

Supplier i / Growers j	1	2	3
1	650	0	700
2	1000	0	200
3	0	250	0
4	350	950	800
5	0	400	1200
Total	2000	1600	2900

Source: Author's calculation.

The research framework is undertaken in three main stages. In the first stage, supplier criteria are evaluated through existing literature reviews; the level of rainfall and temperature are identified as the most critical parameters affecting the quality and price of coffee beans. By applying the combination of the price regression function with Grey (1,1) and Fourier series, the result shows the Fourier series is more accurate in estimating the variation level of rainfall and temperature. Therefore, the Fourier series is used to anticipate the variation level of rainfall and temperature in six consecutive years (2023–2028) based on the historical data (2017–2022). In the second stage, the regression model of forecasting price is fully calculated. In the final stage, single-objective linear programming is useful for dealing with multi-criteria decision-making problems where the weight of criteria and assumptions for the between optimal price and cost.

5. Conclusions

The comprehensive selection criteria based on the hybrid model help improve the company's decision of choosing the right supplier. An appropriate supplier makes a great difference in enhancing and costing optimization, diversifying export capacity, and capturing opportunities for the growth of the Vietnamese coffee industry. The model of statistical analysis plays an important role in assessing the value of rainfall and temperature. As a result, it indicates that it undoubtedly has a tremendous impact on the average price of coffee beans. The combination method of Grey forecasting and the Grey Fourier series associated with the model of Binary Linear programming provides the predicted price of Vietnamese coffee beans, which is driven to an optimal solution helpful to address the current problems. The anticipation of the future price is solved carefully by applying the Grey Fourier series model. In addition, the findings prove that price and location change are determinants for the decision of supplier selections, and the supplier shortage is causing a huge problem for the coffee industry. The main objective of this paper was to demonstrate the empirical analysis based on mathematics perspectives aimed at optimizing the development of coffee domestic supply networks. The research provides businesses and manufacturers with empirical solutions for determining future risks and improving the capacities to react against external risks.

The integrated approach also provides empirically worthwhile results for the overall development of the agriculture supply chain. The research framework offers feasible solutions for determining qualitative and quantitative factors affecting the success of purchasing and supply management professionals. The study improves the Vietnamese coffee supply network under fluctuating uncertainties such as climate change, price breaks, and government policy toward agricultural products. As a result, big data combined with forecasting the price of coffee beans can enhance supplier selection networks and improve coffee grower productivity, ultimately bringing greater profits to this sector. As this research is the first to propose the approach of Grey theory and single-objective linear programming to be applied in the agriculture industry, there are still some limitations, restrictions, and difficulties in combining these methods. In addition, the researchers could not investigate different variables, which could generate a more accurate result. Therefore, future studies are required with different assumptions.

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