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Analyzing the Effects of Covid-19 on Food Supply Chains: A Case Study on Ranking the Obstacles with ANP Methodology

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Abstract: Coronavirus pandemic has severely affected the supply chain network of many industries. Various activities have been disrupted throughout supply chains due to the increasing number of patients, death rate growth, quarantine regulations, social distancing, closed borders, and the phenomenal decrease in travel rate. Furthermore, the pandemic had dramatic effects on consumers’ behavior all over the world, making them more eager/reluctant to purchase certain industrial products. In this paper, considering the actual supply chain of an Iranian company, the disruptive obstacles that the pandemic can create against properly undertaking activities in a food supply chain, are investigated. The examined obstacles are ranked and prioritized using the Analytical Network Process (ANP) technique. For this purpose, pairwise comparison questionnaires have been designed and completed by 28 managers and supervisors active in the food supply network. The answers are collected and the geometric mean of the matrices and their incompatibility rates are calculated. Based on the obtained results “labor shortage” and “low flexibility” have respectively the highest and lowest priorities among all analyzed obstacles.

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1. INTRODUCTION

Nowadays the business environment has become unpredictable. Supply chains face challenges such as sanctions, human error, system error, natural disasters, and so on. The occurrence of these disorders is natural and inevitable (Umar & Wilson, 2021). The coronavirus pandemic is one of the major challenges that has plagued supply chains in recent years. In the past, Influenza virus outbreak in 1918, 1957, and 1968 affected many, but Covid-19 is quite different, as it has disrupted daily life, businesses, occupations and economic activities (World Health Organization, 2020). Since the Covid-19 outbreak, researchers have studied the risks associated with this event and proposed coping mechanisms to manage the ripple effect and mitigate the supply chain disruptions in different areas including logistics, distributions, and transportation (Ivanov, 2021; Ivanov & Dolgui, 2021).

The Covid-19 outbreak is not the first crisis that was faced by supply chains. Just as meteorological events, political and economic tensions, and natural disasters raise concerns about the resilience of global supply chains, the pandemic can also affect them to various degrees (oecd, 2020). From the beginning of 2020, food systems have been severely disrupted by the outbreak of the coronavirus.

Food Supply Chain (FSC) is a set of activities including supply, processing, production, distribution and consumption. Natural disasters can affect many of these activities from cultivation of raw materials to transportation and sales (Reddy et al. 2016). In general, the food industry has been hardly hit by the pandemic. The outbreak of the virus has changed the behavior of customers, manufacturers and suppliers and affected the supply and demand of goods. Industries need to take conventional and immediate actions to mitigate the effects of severe disruptions that are rapidly spreading throughout the supply chain network. Producers have been under a lot of pressure and there seems to be an initial reaction phase in which, firms and manufacturing industries are forced to focus on short-term, practical initiatives to deal with the preliminary phases of these disruptions.

2. RELATED LITERATURE

The COVID-19 pandemic has created many difficulties for food systems. The closure of the food production industries, changes in purchasing behavior, disruption of the transportation network, and the labor absence are all factors that have created challenges in the FSC (Nakat & bou-mitri, 2021). Hereafter, some of the challenges caused by the coronavirus outbreak in different levels of the food supply chain are analyzed from different aspects.

2.1 Food distribution networks

Food distribution networks have been disrupted for almost all income groups, with severely negative results for the most
vulnerable layers; Decreased purchasing power of workers on forced leave and reduced incomes, home quarantine and limited physical access to food markets, decreased demand in institutions that support food networks such as food banks and school nutrition programs, market disruptions such as problems with supermarkets ability to quickly charge warehouses from centralized distribution centers following unprecedented demand for major items, and increased disposal of agricultural or dairy products due to their late transfer from production to local markets (Stephens et al., 2020).

2.2 Health of employees

World Health Organization (WHO) has ruled out transmission of the coronavirus through food and packaging because the virus is not stable at less than 70 degrees (Mahmoud, 2020). Nevertheless, positive virus test results on frozen shrimp packaging and carrying containers (Net Ease, 2020) and on frozen chicken wings (Pei, 2020) showed that the virus could be more stable at low temperatures. These results posed a serious threat to people who work in food processing plants and have led to disruption in their work. Moreover, coronavirus survives on metal and plastic surfaces for a long time. Hence, sectors must follow certain protocols such as the use of gloves, masks and practice social distancing (Rizou et al., 2020).

2.3 Manpower shortages

Restrictions on outdoor activities in addition to restrictions on transportation and travel caused shortage of manpower and input resources, which affected activities in the FSC (harvesting, processing and distribution). Freshly harvested crops can’t reach their destinations and become corrupted on farms, leading to short-term and long-term food shortages.

2.4 Increased demand for products

The biggest issue during a supply chain crisis is maintaining its coherence. In a pandemic, the demand for food increases in all countries. In one study, requests in European countries were evaluated during the coronavirus pandemic. Demand for fresh bread and vegetables increased by 76 and 52 percent respectively in the week following the outbreak. Demand for alcoholic beverages also increased a month after the announcement of the pandemic (Barman et al., 2021).

The closure of grocery stores has disrupted the FSC as well. Increased customer demand leads to empty shelves and also decreased level of supply increases the prices of items. Governments face financial pressure due to economic losses and the allocation of their assets to aid programs. It is imaginable that inexpensive financing may reduce the demand for food products (Rowan and Galanakis, 2020). In a pandemic, higher food prices can cause reduced food diversity. Apart from food prices, food and supply chain disruptions may lead to a lack of availability and affordability for a variety of foods (Harris et al. 2020).

2.5 Lack of flexibility and delay in chain activities

Delayed activities in crop harvesting, inventory and warehouse management, transportation and distribution can cause serious problems in the entire FSC (Tabak, 2020). Flexibility of the production systems in the COVID-19 pandemic is another issue faced by many companies (Stephens et al., 2020). With the diffusion of the virus in 2020, much attention has been paid to the flexibility of FSCs. To maintain their position, FSCs must be able to adapt to shocks as quickly as possible (Hobbs, 2020).

2.6 Trade and transportation

The virus has also had a profound effect on global agricultural trade and international relations (Stephens et al., 2020). With restrictions and border closures, food exports are reduced and therefore, food supply cycles all over the world are economically deprived. As a result of quarantine, shipping of agricultural raw materials from rural to urban areas has faced problems. Also, road restrictions imposed by governments created challenges for transportation in the production and distribution sectors. Travel restrictions during the outbreak left many countries without the economic benefits of tourism (Mamirkulova et al., 2020).

The obstacles listed in Table 1 are extracted from articles on the food supply chain or other supply chains affected by the Corona pandemic. The most important of them were identified from the literature of the subject and then, according to the experts of the company, those which were more related to the supply chain of Golestan Company were selected.

### Table 1: Food industry chain obstacles during the pandemic

| Obstacles                        | Source                                                                 |
|----------------------------------|------------------------------------------------------------------------|
| Transportation                  | Deconinck et al., 2020; Hobbs, 2020; Iese et al. 2021; Nakat and bou-mitri, 2021; Barman et al., 2021 |
| Delay                            | Tabak, 2020                                                            |
| Labor shortage                  | Nakat and bou-mitri, 2021; Hobbs, 2020; Barman et al., 2021; Stephens et al., 2020 |
| Limited storage capacity        | Tabak, 2020                                                            |
| Food health                      | Mahmoud, 2020; Pei, 2020                                              |
| People’s health                  | Rizou et al., 2020                                                    |
| Border closures                 | Mamirkulova et al., 2020; Barman et al., 2021                         |
| Panic demand                     | Hobbs, 2020; Brusset & Teller, 2017; Liu et., 2018; Barman et al., 2021; Rowan and Galanakis, 2020; Stephens et al., 2020; Ponte et al., 2019 |
| Decreased supply                | Hobbs, 2020; Rowan and Galanakis, 2020; Ponte et al., 2019; Brusset & Teller, 2017; Liu et., 2017; Tabak, 2020 |
| Low Flexibility                  | Hobbs, 2020; Stephens et al., 2020                                   |

As can be seen, many researchers have examined challenges in a single stage of the FSC. Most of the studies have merely analyzed obstacles in agriculture sector and the few studies that have considered the whole FSC are basically reviews of the literature. The main contribution of this paper is analyzing and considering challenges and obstacles in all sectors of the FSC including agriculture, production, distribution and sales. The effects of these obstacles on each part of the FSC are also further investigated.

### 3. PROBLEM STATEMENT

Covid-19 in the FSC negatively affects agriculture, farm products’ processing, transportation, logistics and final demand. Not all sectors and products are equally affected, but all products are disrupted at different stages of the supply chain (Deconinck et al., 2020). Food companies are different from other companies because they produce essentials of our daily...
lives (Staniforth, 2020). In this study, the effects of coronavirus on the supply chain of Golestan Food Industries (an Iranian company that operates in the field of production and packaging of food products) is investigated. To do so, based on the reviewed literature, the supply chain obstacles in the company are identified and later ranked according to their importance by means of Analytical Network Process (ANP) technique. In the 70’s, Golestan company expanded its product portfolio to more than 20 main food groups and established a wide sales and distribution network using modern technology. The company is a great example of a FSC including different suppliers and consumers.

### 3.1. Assumptions

- The supply chain consists of multiple products.
- Golestan Company is responsible for different stages of production from planting to distribution.
- Manpower is needed in all segments of the chain.
- There is a possibility of food being contaminated by the virus in the path towards packaging.
- Food storage capacity is limited at harvesting and distribution warehouses.
- Tourists are part of the retail customers.

### 4. RESEARCH METHODOLOGY

The proposed research framework is shown in Figure 1.

![Research Framework Diagram](image_url)

This framework is a slightly modified version of a similar one presented by Chitrakar et al. (2021). In their research Chitrakar et al. (2021) aimed at reducing human contacts with each other as well as human contacts with food, by means of new technologies. The only components in their research are manpower and transportation. Also, agriculture sector is not considered in their proposed framework. The main participants of this study are managers and experts active in the field of food production of Golestan company.

**Shipping issues**
- Transportation of agricultural products
- Carrying processed products in the factory
- Shipping from distribution centers to retail centers

**Labor shortage**
- Agricultural manpower
- Manpower in the production sector
- Manpower in the distribution sector

**Food health**
- Not becoming infected with the virus at the time of cultivation and harvest
- Not being contaminated before packaging

**Manpower health**
- Not being contaminated with raw materials in the pre-packaging stage
- Customer health after opening the package and using it

**Low Flexibility**
- Existence of strategy in times of crisis in the production sector
- Existence of strategy at the time of high demand in distribution centers

**Limited storage capacity**
- Corruption of raw materials in the agriculture sector
- The non-responsiveness of the distribution sector to panic demand

**Delay**
- Delays in harvesting and collecting
- Delays in production activities
- Delays in distribution

**Borders closure**
- Lack of fertilizers and pesticides in agriculture sector
- Reduction of exports in the production sector
- Fewer tourist arrivals as customers in the retail sector

**Decreased supply**
- Disruption in the activities of key suppliers in agriculture sector
- Decreased production
- Rising prices in distribution centers
- Rising prices in retail centers

**Panic demand**
- Inability to predict demand in the production sector
- Occurrence of hoarding in distribution centers
- Product shortage in retail centers

Due to the large number of people eligible for participating in the survey, Krejcie and Morgan (1970) table was used to determine the proper sample size. This sample includes 28 managers and experts working in different departments such as production planning and inventory control, sales, logistics, product development, human resource management, and data analysis. Library and field data collection method was used in this research. The most important research tool in this study is the questionnaire. In order to rank supply chain obstacles in Golestan company, through library studies and theoretical foundations related to the research topic, obstacles (alternatives) have been identified. These alternatives are ranked based on the answers to the questionnaires filled by experts. After compiling the questionnaires, their validity and reliability are examined through the incompatibility rate. The results of the impact of criteria on each part of the supply chain is shown in Figure 2. For example, closing borders will lead to shortages of fertilizers and pesticides in agriculture, reduced exports in the manufacturing sector, and reduced tourist arrivals, i.e., retail customers.
5. THE PROPOSED ANP METHODOLOGY

Figure 3 shows the network drawn in the Super Decisions software (version 2.10.0) including the goal, criteria, and alternatives. In ANP method in addition to the relationships shown in this figure, there is an internal relationship between each criterion and the other three criteria. The circle represents internal dependence and other communications represent external dependence. Because there are interrelationships between criteria, our model is actually a network that considers the interactions and feedbacks between criteria and alternatives.

5.1 Formation of pairwise comparison

At this stage, pairwise comparisons are first created and presented to experts in the form of a questionnaire. The answers are collected and merged by the geometric mean method. Pair comparisons are based on Saaty 9 Quantitative Scale. The results are as shown in Tables 2-7. Three other matrices similar to Table 7 are obtained for the other criteria.

Table 2. Paired comparison matrix of criteria with respect to the target

| Criteria          | Agriculture | Production | Distribution | Retailing |
|-------------------|-------------|------------|--------------|-----------|
| Agriculture       | 1.000       | 1.388      | 1.066        | 1.322     |
| Production        | 0.720       | 1.000      | 1.314        | 2.185     |
| Distribution      | 0.938       | 0.761      | 1.000        | 1.571     |
| Retailing         | 0.757       | 0.458      | 0.636        | 1.000     |

Table 3. Paired comparison matrix of agriculture sub-criteria

| Criteria          | Labor shortage | Limited storage capacity | Shipping issues | Delay | Food health | Borders closure | Decreased supply |
|-------------------|----------------|--------------------------|-----------------|-------|-------------|-----------------|------------------|
| Labor shortage    | 1.000          | 1.327                    | 1.747           | 0.794 | 1.174       | 2.621           | 2.566            |
| Limited storage capacity | 0.754       | 1.000                    | 1.037           | 1.781 | 2.590       | 1.402           | 1.616            |
| Shipping issues   | 0.572          | 0.964                    | 1.000           | 3.067 | 0.679       | 1.813           | 1.116            |
| Delay             | 1.260          | 0.561                    | 0.326           | 1.000 | 1.669       | 1.515           | 1.860            |
| Food health       | 0.852          | 0.386                    | 1.472           | 0.599 | 1.000       | 1.303           | 1.180            |
| Borders closure   | 0.382          | 0.713                    | 0.552           | 0.660 | 0.767       | 1.000           | 1.265            |
| Decreased supply  | 0.390          | 0.619                    | 0.896           | 0.538 | 0.847       | 0.790           | 1.000            |

Table 4. Paired comparison matrix of production sub-criteria

| Criteria          | Labor shortage | Manpower health | Shipping issues | Delay | Food health | Borders closure | Decreased supply |
|-------------------|----------------|-----------------|-----------------|-------|-------------|-----------------|------------------|
| Labor shortage    | 1.000          | 1.761           | 1.354           | 1.563 | 1.105       | 1.413           | 2.026            |
| Manpower health   | 0.568          | 1.000           | 2.303           | 1.907 | 1.401       | 0.803           | 0.693            |
| Shipping issues   | 0.739          | 0.434           | 1.000           | 1.198 | 1.360       | 1.425           | 1.022            |
| Delay             | 0.640          | 0.524           | 0.815           | 1.000 | 1.556       | 1.384           | 0.659            |
| Food health       | 0.905          | 0.714           | 0.735           | 0.644 | 2.000       | 0.893           | 1.172            |
| Borders closure   | 0.708          | 1.245           | 0.702           | 0.729 | 1.350       | 1.000           | 1.427            |
| Decreased supply  | 0.494          | 1.444           | 0.979           | 0.564 | 0.564       | 0.701           | 1.000            |
| Low flexibility   | 0.390          | 1.609           | 0.858           | 0.582 | 0.582       | 0.556           | 1.401            |
| Panic demand      | 1.011          | 0.719           | 0.959           | 1.367 | 1.367       | 0.579           | 0.578            |

Table 5. Paired comparison matrix of distribution sub-criteria

| Criteria          | Labor shortage | Limited storage capacity | Shipping issues | Delay | Low flexibility | Panic demand | Decreased supply |
|-------------------|----------------|--------------------------|-----------------|-------|----------------|--------------|------------------|
| Labor shortage    | 1.000          | 2.461                    | 2.229           | 2.770 | 1.676          | 1.930        | 1.500            |
| Limited storage capacity | 0.406      | 1.000                    | 2.311           | 1.715 | 0.987          | 1.662        | 0.948            |
| Shipping issues   | 0.449          | 0.433                    | 1.000           | 1.088 | 1.749          | 1.493        | 1.150            |
| Delay             | 0.361          | 0.583                    | 0.919           | 1.000 | 1.253          | 1.475        | 1.093            |
| Low flexibility   | 0.597          | 1.013                    | 0.572           | 0.798 | 1.000          | 1.167        | 1.731            |
| Panic demand      | 0.518          | 0.602                    | 0.670           | 0.678 | 0.857          | 1.000        | 0.853            |
| Decreased supply  | 0.667          | 1.016                    | 0.870           | 0.915 | 0.578          | 1.173        | 1.000            |

Table 6. Paired comparison matrix of retailing sub-criteria

| Criteria          | Customer health | Borders closure | Panic demand | Decreased supply |
|-------------------|-----------------|-----------------|--------------|------------------|
| Customer health   | 1.000           | 3.246           | 1.651        | 1.387            |
| Borders closure   | 0.308           | 1.000           | 1.155        | 1.122            |
| Panic demand      | 0.606           | 0.866           | 1.000        | 0.896            |
| Decreased supply  | 0.732           | 0.891           | 1.116        | 1.000            |

Table 7. Paired comparison matrix of criteria compared to agriculture

| Criteria          | Production | Distribution | Retailing |
|-------------------|------------|--------------|-----------|
| Production        | 1          | 3.19513      | 1.05988   |
| Distribution      | 0.31298    | 1            | 0.83406   |
| Retailing         | 0.9435     | 1.19895      | 1         |

5.2 Calculation of incompatibility rates

In the ANP method, the pairwise comparison matrix must be consistent for that pairwise comparison to be acceptable. The Gauss and Butcher (1998) method was used to calculate the incompatibility rate of pairwise comparison matrices. Incompatibility rate is one of the most important parameters in pairwise comparisons. This rate indicates whether comparisons can be trusted and whether pairwise comparisons are valid. Incompatibility rates are calculated for all pairwise comparison matrices (shown in Table 8) and it is observed that all rates are less than 0.1, which indicates that the obtained weights of the indices can be trusted.

Table 8. Matrix incompatibility rates

| Matrix                          | Incompatibility rates |
|--------------------------------|-----------------------|
| Criteria with respect to the target | 0.024     |
| Agriculture sub-criteria        | 0.057     |
| Production sub-criteria         | 0.047     |
| Distribution sub-criteria       | 0.032     |
| Retailing sub-criteria          | 0.038     |
| Criteria compared to Farming    | 0.082     |
| Criteria compared to Production | 0.086     |
| Criteria compared to Distribution | 0.071    |
| Criteria compared to Retailing  | 0.003     |
5.3 Measurement Model Evaluation

Using the weights obtained in the previous section, the initial super-matrix is formed. When the weights of the main criteria are determined based on their purpose and their internal relationships, and the weights of the sub-criteria are determined in their cluster, the eigenvectors of all these matrices could be put together to form a super-matrix. This initial super-matrix is normalized by the linear method and becomes a weighted super-matrix. The weighted super-matrix is then infinitely powered to converge, and the converged matrix is a limit super-matrix as shown in Table 9.

| Goal                     | Goal                  |
|-------------------------|-----------------------|
| Borders closure         | 0.0505                |
| Decreased supply        | 0.0611                |
| Delay                   | 0.0514                |
| Low Flexibility         | 0.0249                |
| Food health             | 0.0343                |
| Labor shortage          | 0.0777                |
| Limited storage capacity| 0.0437                |
| Manpower health         | 0.0618                |
| Panic demand            | 0.0539                |
| Production              | 0.1481                |
| Retailing               | 0.1015                |

The weight of the criteria obtained from the limited super-matrix can be seen in Table 10. Among the four criteria, the agriculture sector has the highest weight and is therefore especially important. According to Figure 4, the most important obstacle is the labor shortage in the supply chain of Golestan Food Industries. Manpower health, decreased supply, transportation issues and delays are next in the ranking. In the normal column, the priority of each option is displayed based on the pairwise comparison form and is the most common way to view the results. The ideal column is obtained by dividing the values of each of the numbers in the normal column by the largest number in this column, so the numeric value of the selected option always equals 1.

| Name                      | Graphic    | Id eals | Normal     |
|---------------------------|------------|---------|------------|
| Borders closure           |            | .650911 | .010227    |
| Decreased supply          |            | .787427 | .122385    |
| Delay                     |            | .662241 | .102928    |
| Food health               |            | .442258 | .068784    |
| Labor shortage            |            | 1.000000| .155424    |
| Limited storage capacity  |            | .363211 | .087536    |
| Low flexibility           |            | .320577 | .049283    |
| Manpower health           |            | .795921 | .123707    |
| Panic demand              |            | .518386 | .080570    |
| Shipping issues           |            | .693679 | .107814    |

One of the negative effects of coronavirus outbreak on the food chain of Golestan Company is the delay faced in planting and harvesting activities, delays in production activities, and delays in product distribution. The delay factor can be the result of labor shortages due to illness, quarantine, social distancing regulations or even a drop in the number of vehicles and drivers.

With the enactment of country laws during the pandemic and the closure of borders, the import of agricultural necessities such as fertilizers and pesticides are decreased. Exports of the products are also reduced or even stopped for health reasons. The number of foreign tourists and travelers who are potential customers of restaurants and food retailers decreases as the borders close.

Limited storage capacity is yet another important obstacle which can lead to food spoilage in the agriculture and distribution sector. In times of crisis, with panic demand, production experts are usually unable to accurately predict demand. In distribution centers, hoarding may take place and in retail stores, customers may face a shortage of the product they need.

Food health factor is not as important; this is probably due to the occurrence of the pandemic, the controllers become stricter and in the agriculture and production sectors, health of products is controlled by performing multiple consecutive tests. The least important obstacle of chain is low flexibility in production and distribution. A chain that can implement the strategies defined in times of crisis will overcome this obstacle. It can be said that Golestan Food Industries will become a flexible supply chain if the problems of "manpower shortage", "manpower health", etc. are solved.

6. CONCLUSION

The COVID-19 pandemic in 2020 has been the most destructive calamity of the past generation in terms of its effects on global supply chains. With the onset of the pandemic, the business environment is more competitive. In this study, the effects of the pandemic on FSC are examined. The identified and selected disruptive factors can affect all stages of a FSC from crop plantation to customer use. These factors (problem criteria) were presented to the sample community as matrices of pairwise comparisons. Then, the priority of each obstacle over the other was determined by the managers and the answers were entered into super decisions software ver2.10.0 and the results were analyzed by...
prioritizing the criteria. Among the supply chain sections, agriculture and distribution, and among the chain obstacles, labor shortage and low flexibility had the highest and lowest priorities, respectively.

Trades in goods and services around the world are highly interrelated and disaster sensitive. There is a potential for vulnerabilities in FSCs in the event of sudden shocks. As a result of this long-lasting pandemic, it is necessary to learn about how FSCs respond to crises and to develop strategies to increase supply chain flexibility, reliability, robustness, stability and viability. Furthermore, FSCs can overcome some of these obstacles through food service flexibility, parallel supply chains, consumer flexibility, disaster testing, and import and export dependency analysis. Major crises throughout history were the main reasons behind changes, revisions, rearrangements, and breakthroughs. By correctly analyzing complicated situations many obstacles can be removed in the path towards future progress.

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