Risk management of chilli supply chains using weighted failure mode effect analysis

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Abstract. Chilli supply chain is very vulnerable to risk due to scattered production centre, large number of actors along supply chain. Hence, risk management of chilli supply chain is very crucial to be executed in order to reduce the losses received by farmers and traders. The study aims to (i) identify and assess supply chain risks, and (2) arrange efforts to manage risks in the chilli supply chain. Weighted Failure Mode Effect Analysis (WFMEA) enriched by Analytical Hierarchy Process (AHP) was implemented to evaluate high-risk priorities and to manage those risks. The results showed that risk in marketing chain got the highest priority to be controlled since the greatest potential failure occurred in this channel with the weighted Risk Priority Number about 647.3. Risk indicators in this channel were cashless payment, major harvesting, and price fluctuations. Strategies to manage those risks were the provision of storage warehouses, planting time arrangements, bailout funds for cash purchase, harvest and post-harvest technology and farm capital loan. Government supports was required for providing the small-scale storage, home scale ozonation technology to extent the chilli shelf life and improve the product quality as well as policies on accessible farmer’s credit with farming guarantee system.

1. Introduction
Pandemic Covid-19 has made a comprehensive change on global supply chain. Many production compilations have stalled and transportation companies are reducing operations resulting in disrupted goods distribution. According to a recent research study conducted in early 2020 by SAP and Oxford Economics with 1,000 supply chain executives, with a COVID-19 pandemic, most companies are currently looking for future supply chain management by setting a new clear strategic goal supported by appropriate tools and assistance to reduce risk in the normal new times. Further, During the Covid-19 pandemic, Indonesia experienced supply problems related to chili, sugar and eggs. This condition needs a rapid control effort, especially on chili, since chili is one of high economic value vegetable product in Indonesia.

According to [1], as one of high economic vegetables, chilli become a national concern since the last few years because the highest price fluctuations occurred in this commodity with a price variation coefficient of 27.43% in the farm gate level and 33.85 % in the final market. Coupled with Covid 19, actors along chilli supply chain face the falling price of chilli due to barrier on the transportation and market construction. Chilli farming in District of Cianjur as a buffer of markets in Jakarta, for instance, gets very cheap retail prices at Rp 5000 kg⁻¹.
Commonly, agricultural supply chain is more complex since the process of cultivation and harvest really depends on the season, sizes and shapes of agricultural products are very diverse, production centres are spread widely in several area with small production volume and many actors involve along the supply chain as well [2,3]. Further, the flow of goods, information and financial that occur simultaneously in the modern supply chain nowadays makes the supply chain work more complicated to ensure products arrive to the consumers at the right amount, in the right place and in a cost-effective way [4].

Complexity and length of agricultural supply chain also led to the vulnerable of risk. Even the supply chain risk of agricultural products becomes more difficult to manage due to high uncertainty. This potential risk arises because it triggered by natural conditions that difficult to be predicted, lack of coordination in product distribution between producers and market participants, long distances from production points to sales points and high logistics costs. In addition, changing economic conditions require efficient management of supply chains for agricultural products [5]. Likewise, the chilli supply chain that has the potential to experience disruption including low productivity and continuity of production and non-transparent price information requires the systematic risk management along the supply chain. Related to these conditions, this study aims to (1) identify and assess the risk of chilli supply chain and (2) arrange risk efforts to minimize the failure of risk.

Supply chain management of agricultural products face high complexity, since cultivation and harvest process are highly depending on season, characteristic of products is perishable, product have varying shapes and sizes. Furthermore, the flow of goods, information and financial that occur simultaneously in the modern supply chain nowadays makes the supply chain work more complicated to ensure products arrive at the right amount, in the right place and in a cost-effective way [4]. [6] also suggested the complexity and length of the agricultural supply chain led to be vulnerable of risk. Even the supply chain risk of agricultural products becomes more difficult to manage due to very high sources of uncertainty. This potential risk arises because it was triggered by natural conditions that were difficult to predict from the start, lack of coordination in product taking between producers and market participants, long distances from production points to sales points and high logistics costs. In addition, changing economic conditions require efficient management of supply chains for agricultural products [5]. Likewise, the chili supply chain which has the potential to experience disruption including low productivity and continuity of production and non-transparent price information requires systematic supply chain risk management. Related to these conditions, this study aims to (1) identify and assess the risk of chilli supply chain and (2) arrange risk management efforts to minimize the failure of risk to chilli supply chain.

2. Materials and methods

2.1. Framework

The supply chain is the flow of goods from the point of production to the hands of consumers by observing factors of timeliness, quantity and cost of product. The length of the supply chain and the complexity of interests in the supply chain led to the high possibility of risk in the supply chain process.

Risk is the probability of an event resulting in a loss when the event occurs during a certain period [7]. Further, risk is a potential event that can be detrimental due to the uncertainty of an event [8]. Supply chain risk is mentioned as an event that adversely affects supply chain performance, which is related to the speed of responding to requests, accuracy in fulfilling demand, continuity of meeting demand, and costs [9]. Meanwhile, [4] explained that successful supply chain performance is when shipping the right number of products to the right place can be done efficiently so that risk is said to be the possibility of deviation from expectations that cause losses. Deviations can start from the production input sub-system to marketing so identification of risks should be conducted for each channel in supply chain. Risk management of the chili supply chain is the act of reducing the potential failure in the supply chain by referring to the results of risk assessment. The application of risk
management actions later both preventive and responsive will have a major effect on the accuracy of the supply chain management process [10].

Risk management is a systematic approach to determine efforts to minimize deviant events and losses caused. Risk management on chili supply chain through the stages of risk identification, risk assessment and risk mitigation. Risk identification starts from the main problems faced in the chili supply chain and continues with the preparation of risk indicators in the three chili supply channels i.e., production, post-harvest and marketing chains. Risk assessment aims to determine the greatest risk priority that has a high failure rate. The risk assessment stage mostly uses the Failure Mode Effect Analysis (FMEA) method with a Risk Priority Number (RPN) based on three main indicators namely the severity of loss due to the risk, the frequency of occurrence of risk and the difficulty of detecting risk. In its development, the FMEA method was refined with the Weighted Failure Mode Effect Analysis (WFMEA) approach introduced by [11] because this approach is able to consider the relationship between the importance of risk indicators with supply chain performance, risk assessment and risk mitigation alternatives. The weight of each risk in each supply chain channel was obtained from integration of AHP and FMEA where the weight of each channel from AHP is used as a weight multiplier risk assessment on Risk Priority Number (RPN). The results of the weighted RPN (WRPN) are indicative of the potential failure of each type of risk where the higher the weighted RPN value, the greater the potential failure (risk failure) of these risks and become the main priority to be controlled [7]. Further, risk management is an effort to reduce potential failure by considering the results of WRPN assessment. The implementation of risk management actions, both preventive and responsive will have a major effect on the accuracy of the supply chain process [10].

2.2. Data and method
This research was conducted in Pacet District, Cianjur Regency, Province of West Java. This study used primary and secondary data. Primary data were obtained from interviews and Focus Group Discussion (FGD) with experts engaged in chili agribusiness with the purposive sampling method whereas respondent was chosen deliberately by considering experience, knowledge and expertise in chili agribusiness. Meanwhile, secondary data were obtained from the Central Statistics Agency, the Ministry of Agriculture and the Food Crops Agriculture Service of Cianjur Regency.

Identification of chili supply chain risk in Cianjur Regency was focused on three channels i.e., production, post harvesting and marketing channel. Risk assessment used the Weighted Failure Mode Effect Analysis (WFMEA) in advance of FMEA by weighting three channels in the supply chain that reflected the influence of these channel on supply chain failure. Risk Priority Number shows the importance of these risk indicators to be controlled. Meanwhile, the importance weight of risk indicators was calculated using the pairwise comparison matrix method on Analytical Hierarchy Process (AHP). Further, alternatives of risk control were prepared for three chili supply chains and the prioritization of risk control were determined based on the highest weight of supply channel and risk control from the AHP results.

AHP method was a multi criteria and alternative decision making method that considering all criteria were related to one another [12]. AHP developed by prof. Thomas L. Saaty had been able to solve complex problems when there was very little data and statistical information on the problems faced. The stages of the AHP method was started from the formulation of objective i.e. control supply chain risk that causes failure on chili supply chain, compile the problem decomposition by compiling a hierarchical structure of the main criteria obtained from the literature and experts justification, compiling pairwise comparison matrices and calculating Eigen factor value of each matrix as each weight of each risk control alternatives and choosing high priority alternative with the highest importance weight value. Furthermore, the risk assessment was calculated based on a Weighted Risk Priority Number (WRPN) which was calculated using the equation formula.

$$WRPN_n = f(W_i) \times RPN_n$$ (1)
\[ \text{WRPN}_n = f(W_i) \times S_i \times O_i \times D_i \] (2)

where \( f(W_i) \) was the weight of the channel in supply chain, \( S_i \) was severity of failure for each risk indicator, \( O_i \) was the frequency of failure, and \( D_i \) was the level of failure detection ability. The type of risk that has a high WRPN indicated high priority risk to be addressed [13].

3. Results and discussion

3.1. Identification of chilli supply chain risk

Supply chain for chilli farming business in Cianjur Regency was relatively similar with the chilli supply chain in another region of Indonesia (figure 1). Farmers as actors in the production chain were responsible for providing continuous and high quality production with the efficient cost. Position of chilli farming land which was spread out with small volume of production encouraged the growth of collecting traders (collector) who buy farmers’ crops either in the form of slashes (buying all crops) or buying product with a certain standard. Collector at the village level usually provided farmer a capital loans and even provide loans for the farmer’s family needs as well.

| Channel of Supply Chain | Risk Indicators |
|-------------------------|----------------|
| Production              | Extreme seasons and weather |
|                         | Pest and disease attacks |
|                         | Inefficient cultivation technology |
|                         | Low production capacity |
|                         | Unavailable seeds |
|                         | Limited farmers’ knowledge of cultivation technology |
|                         | Simultaneous planting |
| Post harvesting         | Inadequate harvesting facilities and technology |
|                         | Inadequate post-harvest facilities and technology |
|                         | Limited harvest and post-harvest knowledge |
|                         | High yield losses |
|                         | Transportation process from land to warehouse destroys crop quality |
| Marketing               | Price fluctuation |
|                         | Major harvest |
|                         | Asymmetric pricing information |
|                         | Unstable supply |
|                         | Inadequate storage |
|                         | Unsafe transportation and damage the chili products and |
|                         | Cashless payment (payment due). |

Figure 1. Chili supply chain in Cianjur Regency.
Collectors (collecting traders) had a work relationship with wholesalers and suppliers because collector often got capital from wholesalers and suppliers. Wholesalers as actors in the marketing chain sold chilies to wholesale markets and traditional markets such as the Kramat Jati Central market and the Kemang market. The cleaning, sorting and packaging processes were mostly carried out by collectors and wholesalers. They got a margin price about IDR 3,000 kg⁻¹ to 15,000 kg⁻¹ and this fact was in line with the results of [14] that explained most of value chain was gained by retailer, merchants and wholesalers. Wholesalers at the central market even played significant role in collecting chili from farmer and distributed it to consumer through retailer. Apart from selling to wholesalers, several farmers sold their crops to suppliers who supply chilli to hotels, restaurants, catering and modern markets with certain quality standards. Prices received by farmers from suppliers were quite higher than slash sale at average IDR 10,000 kg⁻¹. However, the sales volume to suppliers was quite small, which was below 50 kilograms per sale and the cashless payment caused difficulties for farmers who need money quickly for farming capital and household. Regarding the supply chain risk, based on interviews and focus group discussions (FGD), there were 18 risk indicators for three supply chains as presented in table 1.

3.2. Risk assessment on chili supply chain

Risk assessment of chilli supply chain by implementing Risk Priority Number approach without considering the importance weight of each part of chilli supply chain showed that risk of production chain had the highest RPN value (1541.8). Risks in the production chain were very detrimental to farmers as actors of production. This result was in line with the cocoa supply chain risk research conducted by [15] where production risk has the highest priority to be controlled to achieve a profitable cocoa business. Meanwhile, supply chain risk assessment using the weighted Risk Priority Number (WRPN) showed marketing chain risk had the highest weighted RPN (647.3) with the weight about 0.71. These results indicated risks in the marketing chain get the highest priority to be controlled since the greatest potential failure occurred in this chain. Further, failure in the marketing chain actually had a multiplier effect on other chain in the chili supply chain. When risks in the marketing chain were not handled properly, it will cause significant losses for actors in the production and post-harvest chains. As a comparison, the results of the RPN and WRPN are still presented to analyse the differences in risk evaluation results in the chili supply chain (table 2).

| Supply Chain | Weight | RPN   | Ranka | WRPN  | Rankb |
|--------------|--------|-------|-------|-------|-------|
| Production   | 0.2007 | 1541.8| 1     | 309.4 | 2     |
| Post Harvest | 0.0847 | 1302.5| 2     | 110.4 | 3     |
| Marketing    | 0.7146 | 905.8 | 3     | 647.3 | 1     |

aRanking for RPN
bRanking for WRPN

Out of seven risk indicators in the marketing channel, cashless payments, major harvesting and price fluctuations were a high priority risk to be controlled as presented in table 3. The risk of cashless payments has RPN 322.9 and it was mainly caused by the severity of losses with score about 8.8. Collector, supplier and wholesaler explained that a cashless payment was greatly disturbed their income and profits because the cash cycle will be slow down and they could not get the working capital immediately. Risk of cashless payment that occurred in the marketing channel also had an impact on farmer payments as well whereas farmers could not get income immediately and encouraged farmers in debt. This result was in line with results of related research by [16] which explained that finance was the most dominant source of risk in the mangosteen supply chain. [6] in the
article about agricultural supply chain risk identification explained more clearly that there were weak abilities to manage financial risk since participants of agricultural supply chain in Ghana effectively managed operational and managerial risk only.

| Supply Chain | Risk Indicator                                                                 | Severity (S) | Occurrence (O) | Detection (D) | RPN     | Rank |
|--------------|---------------------------------------------------------------------------------|--------------|----------------|--------------|---------|------|
| Production   | Extreme seasons and weather                                                     | 5.6          | 4.8            | 5.8          | 155.2   | 5    |
|              | Pest and disease attacks                                                         | 6.7          | 6.1            | 5.0          | 202.8   | 3    |
|              | Inefficient cultivation technology                                               | 6.3          | 5.7            | 4.5          | 159.4   | 4    |
|              | Low production capacity                                                          | 6.9          | 6.3            | 5.0          | 219.0   | 2    |
|              | Unavailable seeds                                                                | 5.4          | 5.6            | 5.0          | 151.2   | 6    |
|              | Limited farmers' knowledge of cultivation technology                              | 5.3          | 4.9            | 4.4          | 115.8   | 7    |
|              | Simultaneous planting                                                            | 7.6          | 7.3            | 6.1          | 334.5   | 1    |
| Post Harvesting | Inadequate harvesting facilities and technology                                | 7.0          | 6.8            | 6.2          | 291.4   | 1    |
|                | Inadequate post-harvest facilities and technology                                | 6.6          | 6.3            | 4.8          | 198.9   | 2    |
|                | Limited harvest and post-harvest knowledge                                       | 6.1          | 6.2            | 4.5          | 168.8   | 4    |
|                | High yield losses                                                                | 6.6          | 5.8            | 5.2          | 198.4   | 3    |
|                | Transportation process from land to warehouse destroys crop quality              | 5.5          | 5.7            | 3.9          | 122.1   | 5    |
| Marketing     | Price fluctuation                                                               | 6.8          | 6.5            | 4.9          | 215.7   | 3    |
|                | Major harvest                                                                   | 7.7          | 6.0            | 4.9          | 226.2   | 2    |
|                | Asymmetric pricing information                                                   | 4.7          | 4.5            | 3.3          | 70.0    | 7    |
|                | Unstable supply                                                                  | 5.4          | 5.4            | 5.1          | 149.1   | 5    |
|                | Inadequate storage                                                              | 6.0          | 5.1            | 5.4          | 165.2   | 4    |
|                | Unsafe transportation and damage the chili products                              | 4.2          | 4.6            | 4.2          | 79.6    | 6    |
|                | Cashless payment                                                                | 8.8          | 7.8            | 4.7          | 322.9   | 1    |

Risk on major harvesting was the second highest potential failure after cashless payment with RPN of 291.4. Major harvesting caused availability of chilli exceed the demand and further caused the price of chilli being very cheap, even lower than the cost of production. In addition, when storage facilities were very limited, it causes huge losses for traders since chillies become rotten.

Major harvesting as a highest priority risk in the marketing chain was closely related to the risk of simultaneous planting in the production chain which also had the highest RPN as well (334.5). This means that simultaneous planting and major harvesting caused losses for both farmers and traders. Farmers got low prices during harvest season and traders as actors in the marketing chain had the potential to suffer losses when they did not have an enough warehouse or storage facility to maintain the quality of fresh chillies. In addition, price fluctuation as the third highest potential failure in marketing chain suffered both traders and farmer. Losses due to price fluctuations were worsened by inadequate ownership of harvesting facilities as indicated by its RPN reaching 291.4 and become the dominant source of risk in the post-harvesting chain. Limited of chilli harvesting facilities caused a big loss because the production quantity and quality was not good since many chillies were damaged.
3.3. Supply chain risk management

Alternative of strategy for controlling the risk proposed by respondents is an effort to reduce the potential failure of such risks to the efficient performance of chilli supply chain. There were 14 alternatives of risk control strategies for three chain i.e., production, post-harvesting and marketing supply chains and risk priority based on weight in AHP approach.

The weight of each alternative of strategy as presented in Table 4 showed that the provision of storage warehouses was the most important risk control (w = 0.233), followed by planting time arrangement (w = 0.219), bailout funds for cash purchases (w = 0.196), harvest and post-harvesting technology (w = 0.062) and farm input/capital loan (w=0.057). Storage warehouse was required to maintain the quality of chillies and encourage the price stability of chilli through adjustment of selling time. The bailout fund was intended to facilitate cash payments to farmers who need fast cash and provide farm capital assistance to farmers as well which can be returned when harvesting time. The planting time arrangement was aimed at avoiding major harvests and further could maintain the supply continuity of chillies every day.

| Alternative risk control strategy                  | Weight | Priority |
|---------------------------------------------------|--------|----------|
| Storage                                           | 0.233  | 1        |
| Planting time arrangement                         | 0.219  | 2        |
| Bailout funds for cash payment                    | 0.196  | 3        |
| Post harvesting / processing technology           | 0.062  | 4        |
| Farm input/capital loans                          | 0.057  | 5        |
| Save on pesticides                                | 0.036  | 6        |
| Fertilization                                     | 0.036  | 7        |
| Improving farmer ability                          | 0.027  | 8        |
| Post harvesting facility                          | 0.026  | 9        |
| Harvesting facility                               | 0.024  | 10       |
| Extends shelf life technology                     | 0.024  | 11       |
| Embung and Pipanization                           | 0.023  | 12       |
| Ajir and hood                                     | 0.020  | 13       |
| Use of mulch                                      | 0.011  | 14       |

Post-harvesting and processing technology included extending chilli shelf-life technology was the fourth most important strategy for controlling supply chain risk since it reduced the risk of product damage and losses in the chilli supply chain. Post-harvest facility that should be provided was the chilli packaging which was able to maintain the moisture content of chillies properly and protect chillies from damage. Technology of extending the shelf life that was very effective in maintaining the freshness of chillies was a small-scale ozonation technology since Indonesian consumers prefer to buy the fresh chillies so that price of chillies will be cheaper immediately when the chillies become dry or being wet. Loan for farming input and capital was other most important risk management strategy that should be conducted to reduce failures on the chilli supply chain. Therefore, government with authority to make policies, has a duty to facilitate obtaining input and capital loans for farmers, either directly or in collaboration with banks and other financial institutions.

4. Conclusions

Identification and risk assessment of the supply chain for chillies showed that the risk of the marketing channel with indicators of cashless payments, major harvest and price fluctuations were high priority risks that must be controlled in the risk management of the chilli supply chain. Risk controls that
should be pursued to be conducted in preventing and minimizing the failure of those risks were the provision of storage warehouses \((w = 0.233)\), planting time arrangements \((w = 0.219)\), bailout funds for cash purchases \((w = 0.196)\), harvest and post-harvest technology \((w = 0.062)\) and farm input/capital loans \((w = 0.057)\). The government could formulate program to provide a small-scale warehouse with home-scale ozonation technology and airtight packaging to maintain the quality of chilli products as well policies to facilitate access to credit with easy collateral and adjustment of loan repayment period in accordance to the harvest periods and the provision of business risk guarantee.

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