Collaboration quality assessment in the sustainable rice supply chain by using an integrated model of QFD-FANP-DEA: A case study of the rice industry in Malang

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Abstract. Collaboration is one of the critical issues in achieving a sustainable supply chain among suppliers and BULOG, the Indonesian Logistics bureau operated by the government that balances economic, social, and environmental aspects. Factors of collaboration behaviour such as commitment, trust, coordination, stability, and continuous improvement are taken into account to support collaboration activities. This study aims to analyse the efficiency score of BULOG and its suppliers and determine the strategy to enhance collaboration quality. This study applied the integrated method of Quality Function Deployment (QFD), Fuzzy Analytical Network Process (FANP), and Data Envelopment Analysis (DEA). The QFD and FANP are to figure out the priority level of the collaboration behaviour factors. Then, DEA serves to calculate the collaboration efficiency score. The result shows that the most important behaviour factor in supporting the collaboration is the coordination, followed by continuous improvement, commitment, stability, and trust. Furthermore, among the nine stakeholders, two stakeholders are inefficient, with the efficiency score of 88.8% and 87.5%. Several strategies that can be applied to achieve the highest efficiency score (100%) are by increasing the sales level and changing the transportation method. Therefore, the economic and the environmental aspects which have a low level can be improved.

1. Introduction

Nowadays, sustainability becomes the main issue in the industrial sectors. Sustainability is related to how to balance economic, social, and environmental aspects in maintaining competitive strategies to achieve optimal benefit at the lowest cost in the supply chain system. A sustainable supply chain is the development of a conventional supply chain system, which focuses on the integration of the triple bottom line (economic, social, and environmental dimensions) in managerial cooperation processes aiming at optimizing the performance of each organisation [1, 2].

Active participation and support from all stakeholders involved are essential to actualising the sustainable supply chain. Commitment and coordination among stakeholders are the basic foundation of the partnership system. Therefore, good collaboration among the stakeholders becomes critical to support the accomplishment of a triple bottom line. Collaboration in the supply chain means an
association between two or more organisations, which share several aspects such as capital, material, technology and information to reach the efficiency and effectiveness of the processes along the supply chain [3-5].

The rice industry is one of the industries that demand good collaboration among stakeholders. Rice is the main staple food in Indonesia, which makes its availability in the market crucial as it is related to the food security in Indonesia. Each stakeholder has a responsibility to ensure the availability of the rice in the market. Therefore, the rice supply chain becomes the main concern for the Indonesian government to ensure that all the stakeholders play their role in the supply chain in efficient and effective ways. Along the supply chain, the rice industry has a partnership with farmers, distributors, retailers, and government, which involves three types of flow, which are material, financial, and information flows.

One of the stakeholders that play a critical role in the rice supply chain in Indonesia is BULOG. BULOG is the Indonesian Logistics bureau operated by the government responsible for the price stability and rice availability in the market. Therefore, BULOG has to maintain a partnership with stakeholders within the rice supply chain. One of the stakeholders that collaborate with BULOG is partnership procurement (MKP). MKP is a legal company whose role is collecting the production yields from the farmers before sent to BULOG. One of BULOG branch which has a large serving area is BULOG Malang. This branch also can adsorb rice production from the farmers, up to 89% [6].

Among the MKP, collaboration does exist in terms of sharing information, assets, and technology. However, maintaining collaboration among the stakeholders is challenging [7]. Commitment, trust, coordination, stability, and continuous improvement play a vital role in collaboration, especially in agro-industries which involve farmers [8]. Commitment is part of the voluntary engagement with others to achieve long-term mutual understanding among stakeholders [9]. Trust reflects the willingness to rely on others to attain mutual benefits [10]. Coordination means communication among stakeholders to reduce the level of ambiguity through a precise mechanism in collaboration [11, 12]. Stability refers to the behaviour that constantly sustains the partnership to achieve long-term benefits [13, 14]. Continuous improvement is an action and ability to enhance the performance that leads to excellent supply chain collaboration [8].

Although the stakeholders in the rice supply chain understand the main factors of collaboration, the collaboration quality, which reflects the effectiveness of the partnership process has never been assessed. Some of the MKP serves partnership with BULOG. Therefore, it is crucial to evaluate which factor that has the most influence in the collaboration between BULOG and MKP in Malang. It is not known which aspects need to be enhanced to support the sustainable rice supply chain. This study aims to evaluate the collaboration quality among BULOG and MKP in Malang by considering the sustainability aspects (economic, social, and environmental) by using the integration of QFD-FANP-DEA. This method has a comprehensive analysis by considering many factors. Therefore, this method will be able to obtain better assessment results compared to other existing collaboration quality assessment methods. Moreover, based on the result, the strategy to improve their efficiency score will be suggested.

2. Materials and Methods

2.1. Data collection
Data collection is started by preparing the questionnaires as the main instrument to collect the data from the experts. There are two sets of questionnaire prepared, pairwise comparison and collaboration quality evaluation form. The pairwise comparison is used to assess the degree of relevance among the collaboration behaviour factors. This questionnaire will be distributed to three experts as the representatives of BULOG and MKP. The questionnaire is in a closed-ended format. Each respondent has to assess the importance degree of each criterion by using the scale of 1-3-5-7-9 that represents equally important, weakly important, strongly more important, very strongly more important, and extremely more important respectively.

Furthermore, the collaboration behaviour assessment is to evaluate the collaboration efficiency score for each stakeholder (BULOG and MKP) in terms of commitment, trust, coordination, stability, and
continuous improvement. This questionnaire is a four-point Likert scale that will be distributed to eight MKP and BULOG. MKP that will be served as respondents involved all the partnership procurements that collaborated with BULOG within the last year.

2.2. **Integrated model quality function deployment - fuzzy analytic network process - data envelopment analysis**

Data were analysed in two stages. Firstly, the importance level of collaboration behaviour factors was analysed by using QFD-FANP. Then, the result from QFD-FANP became the weight in determining the collaboration quality score by using DEA. Two types of variable were applied in this study, including collaboration behaviour factors (DRS) and sustainability factors (SRS). The stages of the integrated model QFD-FANP-DEA can be seen in Figure 1.

2.2.1 *Calculate the consistency ratio (CR)*

Before further analysis, the consistency of the data from the pairwise comparison needs to be evaluated by using the equation as follows [15]. To calculate the consistency ratio, it needs to consider the largest eigenvalue ($\lambda_{\text{max}}$), consistency index (CI), and random index (RI). Data were categorised as consistent if the value of CR < 0.1.

$$\lambda_{\text{max}} = \frac{1}{m} \left( \sum_{i=1}^{m} \frac{\sum_{j=1}^{m} p_i^j w_j^i w_j^i}{w_j^i} \right), \quad i, j = 1, 2, \ldots, m$$  \hspace{1cm} (1)

$$\text{CI} = \frac{\lambda_{\text{max}} - m}{m-1}$$

$$\text{CR} = \frac{\text{CI}}{\text{RI}}$$

2.2.2 *Calculate the overall priorities of collaboration behaviour factors (w*)*

Fuzzy ANP was applied in this study by following Chang’s Extent Analysis Method [16]. In this method, triangular fuzzy numbers (TFN) $M_{gi}^j$ ($j = 1, 2, \ldots, m$) was utilised. The step of this analysis are:

a. The value of fuzzy synthetic extent with respect to the i, object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$$  \hspace{1cm} (2)

while to obtain $\sum_{j=1}^{m} M_{gi}^j$, the fuzzy addition operation of m extent analysis values is achieved for a matrix:

$$\sum_{j=1}^{m} M_{gi}^j = \left( \sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right)$$  \hspace{1cm} (3)

Moreover, to obtain $\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, the fuzzy addition operation of $M_{gi}^j$ ($j = 1, 2, \ldots, m$) values are applied:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left( \sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right)$$  \hspace{1cm} (4)

Then, the inverse of the vector of the previous equation is computed:

$$\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left( \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right)$$  \hspace{1cm} (5)
b. The degree of possibility of \( M_3 = (l_3, m_3, u_3) \geq M_2 = (l_2, m_2, u_2) \) is defined as \( V(M_3 \geq M_2) = \sup_{x \geq y} \left[ \min \left( \mu_{M_1}(x), \mu_{M_2}(y) \right) \right] \). When \( x \geq y \) and \( \mu_{M_1}(x) = \mu_{M_2}(y) = 1 \) and \( d \) is the ordinate of the highest intersection point \( D \) between \( M_1 (\mu_{M_1}) \) and \( M_2 (\mu_{M_2}) \), can be equivalently expressed as follows:

**Figure 1.** Flow diagram of integrated model QFD-FANP-DEA.
\[ V(M_2 \geq M_1) = hgt(M_2 \cap M_1) = \mu_{M_1}(d) \]

\[
= \begin{cases} 
1, & \text{if } m_2 \geq m_1 \\
0, & \text{if } l_1 \geq u_2 \\
\frac{(m_2 - u_2) - (m_1 - l_1)}{m_2 - u_2 - (m_1 - l_1)}, & \text{otherwise}
\end{cases}
\]

(6)

To compare \( M_1 \) and \( M_2 \), both the values of \( V(M \geq M_1) \) and \( V(M \geq M_2) \) is needed.

c. The degree possibility for a convex fuzzy number to be greater than \( k \) convex fuzzy numbers \( M_1 = (1, 2, \ldots, k) \) can be defined by

\[
(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{and } (M \geq M_k)] \\
= \min V(M \geq M_i), \quad i = 1, 2, 3, \ldots, k
\]

(7)

assume that

\[
d'(A_i) = \min V(S_i \geq S_k) \quad \text{for } k = 1, 2, \ldots; n; k \neq 1
\]

Then the weight vector is given by

\[
W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \text{ where } A_i(i = 1, 2, \ldots, n) \text{ are } n \text{ elements}
\]

(9)

The next step is defuzzification to transform \( W' \) into real value by using normalisation. The normalised weight vectors are

\[
W = (d(A_1), d(A_2), \ldots, d(A_n))^T
\]

(10)

where \( W \) is a non-fuzzy number.

2.2.3 **Determine collaboration efficiency score by using DEA**

The assessment of the collaboration quality will conduct output-oriented DEA with a variable return to scale that considers undesirable factors [17] as follow.

\[
\text{min } \sum_{i=1}^{m} u_i x_{i0} - \xi
\]

(11)

Subject to:

\[
\sum_{i=1}^{m} u_i x_{ij} - \sum_{r=1}^{s} v_r \left( \frac{y_{ij}^d - \min_{r=1}^{s} \left( y_{ij}^d \right)}{\max_{r=1}^{s} \left( y_{ij}^d \right) - \min_{r=1}^{s} \left( y_{ij}^d \right)} \right) - \left[ \sum_{s+1}^{t} v_r \left( \frac{y_{ij}^u - \min_{r=1}^{s} \left( y_{ij}^u \right)}{\max_{r=1}^{s} \left( y_{ij}^u \right) - \min_{r=1}^{s} \left( y_{ij}^u \right)} \right) + \beta \right] \geq \xi
\]

\[
0, \quad j = 1, \ldots, n
\]

\[
\sum_{r=1}^{s} v_r \left( \frac{y_{0ij}^d - \min_{r=1}^{s} \left( y_{0ij}^d \right)}{\max_{r=1}^{s} \left( y_{0ij}^d \right) - \min_{r=1}^{s} \left( y_{0ij}^d \right)} \right) - \left[ \sum_{s+1}^{t} v_r \left( \frac{y_{0ij}^u - \min_{r=1}^{s} \left( y_{0ij}^u \right)}{\max_{r=1}^{s} \left( y_{0ij}^u \right) - \min_{r=1}^{s} \left( y_{0ij}^u \right)} \right) + \beta \right] = 1
\]

\[ u_i, v_r \geq \varepsilon \quad \forall i, r, \quad \xi \text{ free in sign} \]

Where \( n \) number of DMU, \( i \) index on input, \( m \) number of input, \( r \) index on output, \( s \) number of output, \( x_{ij} \) amount of input \( i \) consumed by the \( j \)th DMU, \( y_{ij} \) amount of output \( r \) produced by the \( j \)th DMU, \( A_i \) priority scale of input \( i \) of the \( j \)th DMU, \( u_i \) weight of input \( i \), \( v_r \) weight of output \( r \), \( Y^d \) desirable output, \( Y^u \) undesirable output. The total DMU in this study is nine that consists of eight MKP and BULOG. Each DMU has five inputs, which are collaboration behaviour factors (commitment, trust, coordination, stability, and continuous improvement) and three output, which are sustainability aspects (economic, social, and environmental).

3. **Results and Discussion**

This study results in two outputs, which are an important level of collaboration behaviour factors and the efficiency score of each stakeholder. By using QFD and FANP and taking into consideration the sustainability aspects (economic, social, and environmental), the most important factor of collaboration behaviour in supporting the supply chain is coordination (24%). It is followed by continuous improvement (23%), commitment (21%), stability (20%), and trust (13%). The importance level of each industry tends to be different from each other. For example, in the sugar supply chain, the most important
collaboration behaviour factor is commitment. The differences in the priority scale depend on the nature of the collaboration system and the characteristic of the stakeholders [17].

Coordination is the most crucial aspect as it is related to the effective communication of all stakeholders. Between BULOG and MKP, coordination is significant to inform the capacity of the warehouse, the production planning, the availability of material, the standard quality, and the price. Good coordination among stakeholders can reduce misunderstanding and support effective problem-solving processes [18]. Coordination also allows stakeholders to exchange their idea and information for their competitive advantages.

On the other hand, the least important collaboration behaviour factor is trust. The stakeholders consider trust as the last option since they believe that trust automatically underlies this collaboration system. All the MKP that still collaborate with BULOG is loyal organisations that have the confidence to share common goals through this collaboration. An organisation with a high level of trust will take more opportunities and efforts in the partnership system that bring benefits to both parties [9, 19].

Once the level of priority is obtained, the next step is to calculate the efficiency score for each stakeholder that reflects the collaboration quality. This process uses five inputs (commitment (CM), trust (TR), coordination (CO), stability (ST), and continuous improvement (CI)) and three output (economic, social, and environmental). The data input-output of collaboration in BULOG is shown in Table 1.

### Table 1. Data input-output of Collaboration in BULOG.

| DMU | Input | Output | Efficiency Score (%) |
|-----|-------|--------|----------------------|
|     | CM    | TR     | CO      | ST | CI | Economic | Social | Environmental |
| D1  | 2     | 2      | 4       | 1  | 3  | 15,215.81 | 2      | 0.9973        |
| D2  | 3     | 4      | 4       | 4  | 3  | 14,111.06 | 5      | 0.9938        |
| D3  | 2     | 2      | 3       | 2  | 2  | 15,662.25 | 2      | 0.9987        |
| D4  | 3     | 3      | 4       | 3  | 3  | 15,298.43 | 3      | 0.9935        |
| D5  | 3     | 4      | 3       | 3  | 3  | 20,752.08 | 4      | 0.987         |
| D6  | 2     | 3      | 3       | 3  | 2  | 21,348.55 | 2      | 0.9987        |
| D7  | 2     | 3      | 2       | 1  | 2  | 280.04    | 2      | 0.9932        |
| D8  | 2     | 2      | 2       | 1  | 2  | 561.5     | 2      | 0.9941        |
| C1  | 4     | 4      | 4       | 2  | 4  | 12,391.64 | 5      | 0.9996        |

### Table 2. Efficiency score of each stakeholder.

| DMU | Economic ($) | Social | Environmental | Efficiency Score (%) |
|-----|--------------|--------|---------------|----------------------|
|     | Original | Projected | Original | Projected | Original | Projected | Original | Projected |                       |
| D1  | 15,215.81  | 15,215.81 | 2       | 2       | 0.9973    | 0.9973    | 100      |
| D2  | 14,111.06  | 14,111.06 | 5       | 5       | 0.9938    | 0.9938    | 100      |
| D3  | 15,662.25  | 15,662.25 | 2       | 2       | 0.9987    | 0.9987    | 100      |
| D4  | 15,298.43  | 17,198.05 | 3       | 3.1     | 0.9935    | 0.8689    | 88.8     |
| D5  | 20,752.08  | 20,752.08 | 4       | 4       | 0.987     | 0.987     | 100      |
| D6  | 21,348.55  | 21,348.55 | 2       | 2       | 0.9987    | 0.9987    | 100      |
| D7  | 280.04     | 553.94   | 2       | 2       | 0.9932    | 0.8634    | 87.5     |
| D8  | 561.5      | 561.5    | 2       | 2       | 0.9941    | 0.9941    | 100      |
| C1  | 12,391.64  | 12,391.64 | 5       | 5       | 0.9996    | 0.9996    | 100      |
Based on the data, the collaboration quality for eight MKP and BULOG were analysed by using DEA. The profit reflects the economic aspect, the greenhouse gas (GHG) emissions reflects the environmental aspect, and access to financial and non-financial support reflects the social aspect [17]. The efficiency score of 8 MKP and BULOG is presented in Table 2.

It can be seen in Table 2 that to achieve a 100% efficiency score, the value of the triple bottom line must reach the projected value. The result shows that 2 DMU are inefficient (D4 and D7). D7 has the lowest efficiency score (0.875). Efficiency score is classified into three categories, which are efficient (100%), marginally efficient (91%-99%), and inefficient (<90%) [20]. It shows that to achieve the 100% efficiency score, D7 has to improve its profit up to 49.44% and reduce its GHG emissions up to 13.06%. Unlike D7, although D4 has a higher efficiency score compared to D7, D4 needs to enhance its performance in all aspects, which are economic (11.05%), social (4%), and environmental (12.54%).

D4 and D7 are inefficient in the economic aspect (total profit). It is because both DMU, have higher production costs, such as labour costs, administration cost, energy and fuel cost, compared to the value of production output. The high production cost will result in a reduction of the company profit [21]. Therefore, to increase the efficiency score in the economic aspect, the stakeholders can reduce the production cost by applying the efficient process while increasing the sales to enhance the profit.

In regard to the environmental impact, their GHG emissions from transportation activities are higher than other MKP since their location is further away than others. Therefore, the consumption of fuel is higher. Furthermore, the capacity of the truck fleet is much higher than the delivery load, so the GHG emissions per unit product are also higher. Transportation carbon footprint depends on the distance, load, number of delivery, and fuel consumption [22]. Collaboration among the stakeholders can propose an agreement to reduce the GHG emissions by using limited resources during transportation, including the preferred mode of transport [23]. Additionally, D4 also need to enhance their performance in supporting the financial and non-financial aspect, such as support the farmers in seeds, fertiliser, technology, knowledge, and financial assistance for farmers. By providing support and assistance for farmers, the farmers will be loyal and maintain the partnership with the organisation. Moreover, D4 also needs to collaborate with BULOG to give financial and non-financial support to the farmers. Therefore, it will create a robust rice supply chain and bring immense competitive advantages. Providing financial and non-financial support to the collaborative network can help solve the problem, overcome the weaknesses, and reduce the tension; thus, they can give a better performance in the collaboration network [24].

4. Conclusions

Collaboration behaviour factors and sustainability are essential in supporting a robust rice supply chain system. Based on the study, coordination (24%) is the most crucial factor in the rice supply chain collaboration. It is followed by continuous improvement (23%), commitment (21%), stability (20%), and trust (13%). Furthermore, based on DEA result, two stakeholders (D4 and D7) are inefficient among nine stakeholders. They have to enhance their performance in economic, social, and environmental aspects by increasing their profit and financial and non-financial support while reducing the GHG emissions. However, this study may have some limitations that can be improved in further research. The number of DMU can be increased by considering other parties in the supply chain, such as farmers and distributors. Therefore, the analysis of the collaboration in the sustainable rice supply chain is more comprehensive. Moreover, triple bottom line factors also can be further explored to consider other factors such as operational cost, service level, waste, pollution, social welfare, fair trade and transparency.

References

[1] Carter C R and Rogers D S 2008 A framework of sustainable supply chain management: moving toward new theory International Journal of Physical Distribution & Logistics Management 38 360-87
[2] Gimenez C, Sierra V and Rodon J 2012 Sustainable operations: their impact on the triple bottom line International Journal of Production Economics 140 149-59
[3] Cao M and Zhang Q 2011 Supply chain collaboration: impact on collaborative advantage and firm performance Journal of Operations Management 29 163-80
[4] Hamprecht J, Corsten D, Noll M and Meier E 2005 Controlling the sustainability of food supply chains Supply Chain Management: An International Journal 10 7-10
[5] Liao S-H and Kuo F-I 2014 The study of relationships between the collaboration for supply chain, supply chain capabilities and firm performance: a case of the Taiwan's TFT-LCD industry International Journal of Production Economics 156 295-304
[6] BULOG 2019 Profil Perum BULOG (Profile of Perum BULOG). Perum BULOG [In Indonesian].
[7] Dania W A P, Xing K and Amer Y 2019 An Integrated Collaboration Framework for Sustainable Sugar Supply Chains Int. J Sup. Chain. Mgt Vol 8 706
[8] Dania W A P, Xing K and Amer Y 2018 Collaboration behavioural factors for sustainable agri-food supply chains: a systematic review Journal of Cleaner Production 186 851-64
[9] Nyaga G N, Whipple J M and Lynch D F 2010 Examining supply chain relationships: do buyer and supplier perspectives on collaborative relationships differ? Journal of Operations Management 28 101-14
[10] Anbanandam R, Banwet D K and Shankar R 2011 Evaluation of supply chain collaboration: a case of apparel retail industry in India International Journal of Productivity and Performance Management 60 82-98
[11] Saaty T L and Vargas L G 2012 Models, methods, concepts & applications of the analytic hierarchy process (Boston, MA: Springer US)
[24] Uster A, Beeri I and Vashdi D 2019 Don’t push too hard. Examining the managerial behaviours of local authorities in collaborative networks with nonprofit organisations *Local Government Studies* **45** 124-45