Managing risks in the fisheries supply chain using House of Risk Framework (HOR) and Interpretive Structural Modeling (ISM)

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Abstract. One of the sectors which contributes importantly to the development of Vietnam economy is fishery industry. However, during recent year, it has been witnessed many difficulties on managing the performance of the fishery supply chain operations as a whole. In this paper, a framework for supply chain risk management (SCRM) is proposed. Initially, all the activities are mapped by using Supply Chain Operations Reference (SCOR) model. Next, the risk ranking is analyzed in House of Risk. Furthermore, interpretive structural modeling (ISM) is used to identify inter-relationships among supply chain risks and to visualize the risks according to their levels. For illustration, the model has been tested in several case studies with fishery companies in Can Tho, Mekong Delta. This study identifies 22 risk events and 20 risk agents through the supply chain. Also, the risk priority could be used for further House of Risk with proactive actions in future studies.

1. Introduction
The Mekong Delta is one of the great regions contributing to Vietnam’s economy. According to Can Tho University estimation, this region takes account for 70% of nation’s aquaculture areas and 60% of nation’s fish. Nevertheless, the growth rate is low, variable and unsteady. In fact, the common factors affecting the fishery industry are climate change, temperature, uncontrollable weather, flood-tide, disaster and disease. Also, the majority of fishery households in Mekong Delta have small extent of culturing lands, do not aware of cooperating with others as well as how to accommodate with the changing of climate. Moreover, the concerns of protecting environment restricts the using of modern technologies. Besides, some other factors such as quality requirements, production process, transportation, etc., can affect the supply chain as well.

Supply chain risks management is the implementation of strategies to manage both daily and extraordinary among supply chain based on continuous risk assessment. Each partner of supply chain has its risks linking from backward or forward one in supply chain adversely affecting the effectiveness of a whole chain. With the objective of reducing vulnerability and ensuring continuity, SCRM is collaboratively with partners in a supply chain or on your own as well as applies risk management tools to deal with risks and uncertainties caused by logistics related activities and resources in supply chain.

In this approach, we will analyze the activities of partners in supply chain as well as identify problems and essential risks. Some of risks can be solved, diminished, transferred whereas others are
unavoidable. First, SCOR model (Supply Chain Operation Reference) is applied for the purpose of analyzing the activities according to five main stages including plan, resource, make, deliver, and return, of all partners among the fisheries supply chain. Second, using HOR (House of Risk) to assess risks and their roots as well as analyzing the relationship between risks and root causes because they can be caused by different sources and otherwise. Next, the inter-relationships among risks are defined and mapped by ISM (Interpretive Structural Model) to obtain the visual relationship of the problem. To sum up, the purpose of this research is to identify the risk and the source of agent of any risks that affect the process of fisheries in Can Tho, Mekong Delta so that a sustainable fisheries supply chain can be achieved.

2. Literature review

2.1 The supply chain operations reference model (SCOR model)
The supply chain operations reference model (SCOR model) was developed in 1996 by the management consulting firm PRTM, now part of PricewaterhouseCoopers LLP (PwC) and AMR Research, and endorsed by the Supply-Chain Council (SCC). SCOR is a process reference model describes the business activities associated with satisfying a customer’s demand, which include plan, source, make, deliver, and return [1][2]. Use of the model includes analyzing the current state of a company’s processes and goals, quantifying operational performance, and comparing company performance to benchmark data. This reference model enables users to address, improve, and communicate supply chain management practices within and between all interested parties in the extended enterprise.

2.2 House of risk
House of risk is developed upon foundation of well-known model House of Quality (HOQ) but in sense of determining which risk actions to be tackled first and selecting a set of proactive actions deemed cost-effective to be prioritized. It is divided into two phases, House of risk 1 (HOR1) is used to determine which risk agents are to be given priority for preventive actions [3][4][5] whereas House of risk 2 (HOR-2) is to give priority to those actions considered effective but with reasonable money and resource commitments.

HOR first stage as the stage for the data input work has 8 steps as follows:

- Step 1 Identify the activities in the supply chain based on the SCOR model, with a view to facilitate the detection process in which the risk of potentially emerge (where are the risk).
- Step 2 Identify the entire incident risks that may appear on any activity in the supply chain.
- Step 3 Identify Severity Level or degree of impact of each risk event using a scale of 1-10.
- Step 4 Identification result (potential causes) an occurrence of the activity of the supply chain process, as a result will help to describe what disorders arising from any risk.
- Step 5 Identify the agency risk (risk agent), which detects any factors which may cause the occurrence risks identified in step.
- Step 6 Identification of correlation between an event to trigger agent risk. If an agency risk of causing a risk, it can be said there is a correlation. If a strong correlation is weighted 9; correlations are given weights 3 and a weight of 1 to the value of the correlation is weak.
- Step 7 Identify opportunities emergence (occurrence) of each agent risks, to determine the risk of chance occurrence of an agent using a scale of 1-10.
- Step 8 Determination of the risk priority index value, priority will be used benchmark index for recommendation selecting agent which risks need to design a risk mitigation strategy.

2.3 Interpretive structural modeling (ISM)
Interpretive structural modeling (ISM) is a well-established methodology for identifying relationships among specific items, which define a problem or an issue [6][7][8]. This approach has been increasingly used by various researchers to represent the interrelationships among various elements related to the issue. ISM has several steps as follow [9][10][11][12]:

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(1) Identification of variables: The key variables of the system are identified using literature study and brainstorming sessions with the industry experts and academicians.

(2) Contextual relationship: A contextual relationship is identified among each variable (identified in step 1) with respect to which the pairs of variables would be examined. The contextual relationship is in the form of a matrix called the structural self-interaction matrix (SSIM).

Notations used to develop the SSIM:

- V: Risk variable i leads to variable j
- A: Risk variable j leads to variable i
- X: Risk variable i leads to variable j and vice versa
- O: No relationship between the variables

(3) Initial Reachability Matrix (IRM): The SSIM is then converted into a binary matrix, called initial reachability matrix by substituting V, A, X and O by 1 and 0 as per the following rules:

- Rule 1: If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry is 0.
- Rule 2: If the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix is 0 and the (j, i) entry becomes 1.
- Rule 3: If the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.
- Rule 4: If the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

(4) Transitivity check: The reachability matrix is developed from the SSIM and the matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that if variable A is related to B and B is related to C, then A is necessarily related to C.

(5) Levels: The transitivity matrix obtained in step (4) is converted into the canonical matrix format by arranging the elements according to their levels.

(6) Building the ISM model: Variables in each level are then connected based on their relationships as defined in the structural self-interaction matrix.

3. Methods

The data was collected from the companies through questionnaires formed based on the result of SCOR Model and House of risk framework. The sample size consist of 8 small and medium fishery companies located in Can Tho, Mekong Delta from the total of 50 companies (16%). The risk analysis was constructed by risk mapping, risk classifying based on SCOR and HOR. Also, ISM is proposed to identify the relationship among any events of risk for ranking the level of risks. Which risk directly affects to partner of fisheries supply chain will be positioned at level one while the lowest level is the risk that has less affection to partner. It helps us to select which risk should be tackled first in the constraint of budget and resource.

4. Results

4.1. The SCOR model and HOR framework for fisheries companies

Risks and causes found from activities in the planning, source, making, delivery and return of the fisheries supply chain are listed in the Table 1. According to survey, we obtain the aggregated of severity of risks, the probabilities of causes and the correlations among them are shown in Table 2.

| SCOR model | Activities in supply chain | Risks in supply chain (E_i) | Causes of risks (A_j) |
|------------|-----------------------------|----------------------------|----------------------|
| Planing    | Planning product development| Cancel the contract (E1)   | Do not have long-term plan (A1) |
|            | Planning for seafood procession and product quality | Depend on a supplier (E2) | Manage the finance ineffectively (A2) |
|            | Understanding the contract or requirement of customers |                              | Weakness in suppliers selection (A3) |
Table 1. SCOR model with risks and causes of risks at five stages through fisheries supply chain

| SCOR model | Activities in supply chain | Risks in supply chain (Ei) | Causes of risks (Aj) |
|------------|-----------------------------|-----------------------------|----------------------|
| Source     | Build a supplier selection strategy | Natural disaster (drought, flood,…) (A4) |                       |
|            | Forecast the seafood market in the coming time | Environmental pollution (A5) |                       |
|            | Predict the cycle of entering new material sources | Economic crisis (A6) |                       |
|            | The process of sharing information on fishery quality requirements and production lead time for suppliers | Quantity limit (materials, products) from suppliers or sub-contract company (A7) |                       |
|            | Consolidate invoices, pay for the cost of orders | Difficult to compare the suppliers (A8) |                       |
|            | Maintain the relationship with suppliers and sub-contract company | Suppliers or sub-contractors went bankrupt (A9) |                       |
|            | − The price of input materials fluctuate high (E3) | Production techniques are limited (A10) |                       |
|            | − The quality of input materials does not match standardization (E4) |                       |                       |
|            | − Lack of high skilled workers (E5) |                       |                       |
|            | − Lack of capital (E6) |                       |                       |
| Making     | Prepare for production schedule | Changing production plan (A11) |                       |
|            | Planning the amount of workers | Weakness in controlling system (quality of material, product, check hygiene of workers before production…) (A12) |                       |
|            | Maintaining human resources attached to the company | Strict requirements for product (A13) |                       |
|            | Assign human resources among parts of company | Low workers salary (A14) |                       |
|            | Check the quality of products and production process |                       |                       |
|            | Controlling unexpected interruption in production system (devices, human…) |                       |                       |
|            | − Production process is delayed (E7) |                       |                       |
|            | − Devices are out of order in production process (E8) |                       |                       |
|            | − Regularly increasing production time (overtime) (E9) |                       |                       |
|            | − Strike (E10) |                       |                       |
|            | − Lack of materials (E11) |                       |                       |
|            | − Errors in marking components which are used in production process (E12) |                       |                       |
|            | − Products are contaminated, exceeded of proportion of heavy metal (E13) |                       |                       |
|            | − Closed the company (E14) |                       |                       |
|            | − Means of transportation are out of order regularly (E15) | Less maintenance of machinery (A15) |                       |
|            | − Error in delivery (date, amount, type of product, address) (E16) | Regularly late delivery (A16) |                       |
|            | − Delivery time of suppliers change many times (E17) | Long-term shortage of products in stock (A17) |                       |
|            | − Reserved products/ materials are spoiled, increasing inventory cost (E18) | Lack of collaboration with outside organizations (A18) |                       |
|            | − The risks of trade or negotiation with international ports (E19) |                       |                       |
|            | − Exchange rate risks (E20) |                       |                       |
|            | − Do not meet the expectation of customers (E21) | Do not note the orders in detail (wrong date, amount, type of product) (A19) |                       |
|            | − Products are refunded (E22) | Quality of products does not match requirements (A20) |                       |

For examples, we compute ARP as follow:
\[ ARP_1 = O_1 * (R_{11} * S_1 + R_{31} * S_3 + R_{61} * S_6 + R_{14,1} * S_{14} + R_{19,1} * S_{19}) \]
\[ = 5 * (3 * 8 + 9 * 7 + 3 * 5 + 1 * 1 + 1 * 7) = 550 \]

Based on this calculation, the aggregate risk potentials (ARP) are obtained in Table 2.

| Table 2. HOR model |
|-------------------|
| Causes of risk | ARP_1 | Risks |
|-----------------|-------|-------|
| A1 | 3 | 6 | E1 |
| A2 | 3 | 4 | E2 |
| A3 | 3 | 6 | E3 |
| A4 | 9 | 5 | E4 |
| A5 | 9 | 3 | E5 |
| A6 | 3 | 7 | E6 |
| A7 | 3 | 3 | E7 |
| A8 | 3 | 9 | E8 |
| A9 | 9 | 5 | E9 |
| A10 | 9 | 3 | E10 |
| A11 | 9 | 3 | E11 |
| A12 | 9 | 3 | E12 |
| A13 | 9 | 3 | E13 |
| A14 | 9 | 3 | E14 |
| A15 | 9 | 3 | E15 |
| A16 | 3 | 4 | E16 |
| A17 | 1 | 6 | E17 |
| A18 | 1 | 3 | E18 |
| A19 | 1 | 3 | E19 |
| A20 | 1 | 3 | E20 |
| A21 | 1 | 3 | E21 |
| A22 | 3 | 9 | E22 |
| O_j | 5 | 6 | A1 |
| 2 | 1 | 2 | A2 |
| 1 | 2 | 2 | A3 |
| 2 | 3 | 1 | A4 |
| 3 | 2 | 4 | A5 |
| 2 | 4 | 4 | A6 |
| 4 | 4 | 1 | A7 |
| 1 | 2 | 3 | A8 |
| 3 | 2 | 1 | A9 |
| 5 | 4 | 1 | A10 |
| 7 | 3 | 3 | A11 |
| 11 | 12 | 14 | A12 |
| 16 | 14 | 14 | A13 |
| 17 | 13 | 14 | A14 |
| 3 | 8 | 14 | A15 |
| 2 | 20 | 14 | A16 |
| 6 | 10 | 14 | A17 |
| 17 | 8 | 14 | A18 |
| 17 | 15 | 14 | A19 |
| 17 | 14 | 14 | A20 |

| Table 3. Transitional IRM matrix |
|---------------------------------|
| E22 | E21 | E20 | E19 | E18 | E17 | E16 | E15 | E14 | E13 | E12 | E11 | E10 | E9 | E8 | E7 | E6 | E5 | E4 | E3 | E2 | E1 |
| E1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| E2 | 1* | 0 | 1* | 1* | 1 | 1 | 0 | 1* | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| E3 | 0 | 1* | 0 | 1* | 1* | 0 | 0 | 0 | 1* | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| E4 | 1 | 1* | 0 | 1* | 1* | 0 | 0 | 0 | 1* | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| E6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1* | 0 | 1 | 1 | 0 | 0 | 0 | 1* |
| E7 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 1* | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| E8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| E9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| E10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| E11 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| E12 | 1* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| E13 | 1 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| E14 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| E15 | 1* | 1* | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1* | 0 | 1* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| E16 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 1* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

**4.2. Building the ISM model**

At the beginning, based on personal insights and experts’ opinions, we have developed the structural self-interaction matrix (SSIM). Then, we convert the SSIM to the IRM matrix based on the principles developed in step 3 and step 4.
From transitional IRM matrix in Table 3, we determine the level of each risk based on the principles developed in step 5. By dropping the row of risks which have been chosen and these risks in others Reachability set, Antecedent set and intersections simultaneously. Next, keep doing step by step until the risks are filled up. The following table shows the degree of risks.

| Risk | Reachability set | Antecedent set | Intersection set | Level |
|------|------------------|----------------|------------------|-------|
| E1   | 1,7,11,14,22     | 1,2,3,4,5,6,7,8,10,11,12,13,14,15,16,17,18,19,20,21,22 | 1,7,11,14,22 | I     |
| E22  | 1,11,22          | 1,2,3,4,7,11,12,13,14,15,16,17,19,20,21,22 | 1,11,22 | I     |
| E17  | 1* 0 0 0 1 0 0 0 | 1* 0 0 0 1 0 0 | 1* 0 0 0 0 0 0 |   |
| E18  | 0 0 0 0 1 0 0 0 | 1* 0 0 0 1 0 0 | 1* 0 1 0 0 0 0 |   |
| E19  | 1 0 0 1 0 0 0 0 | 0 0 0 0 1* 0 0 | 0 0 0 0 0 0 0 |   |
| E20  | 1* 0 0 0 0 0 0 0 | 0 0 0 0 0 0 0 0 | 0 0 0 0 0 0 0 |   |
| E21  | 0 0 0 0 0 0 0 0 | 1* 0 0 0 0 0 0 0 | 0 0 0 0 0 0 | I   |
| E22  | 1 0 0 0 0 0 0 0 | 1* 0 0 0 0 0 0 0 | 1* 0 0 0 0 0 0 | I   |

| Table 4. Result of level partitioning of reachability matrix. |
Based on the results of level partitioning, we developed the interpretive structural model presented in Figure 1. In this diagram, the risks “Depend on a supplier” (E2) and “Means of transportation are out of order regularly” (E15) are classified in the lowest level (level 9) of the system, with the risks E1 “Cancel the contract” and E22 “Products are refunded” having the highest influence on the others.

5. Discussion and conclusions

There are many types of risks that affect the operation of aquaculture supply chain, but we just focus on the most common types of risks that regularly occur. Results showed that 22 risk events and 20 risk agents are identified, and the two most important risks are A1 “Do not have long term plan” and A13 “Strict product requirement”. This risk priority information will be used effectively for further House of Risk with proactive actions. Moreover, ISM model is used to identify the relationship among risks and draw a relationship diagram so that companies may have a general knowledge of which risks will directly or indirectly influence on their supply chains.

In conclusion, the paper proposes a model for the Risk mapping and Risk priority calculation using ISM and SCOR-HOR for the applications in fisheries supply chain. The findings would help managers to analyse and to take actions for managing the risk factors to improve the performance of their organizations effectively. However, the sample size of experts is small and to remove the biasness of opinion, the model can be further validated using Structural Equation Modelling (SEM) in the future.

In addition, the dependencies between risk events or relative severity of risk events can be further analysed by combining between Analytical Network Process (ANP) and Interpretive Structural Modelling (ISM).
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