

Multi-hierarchical Framework – Fuzzy Entropy Weight Approach for Auditing Technology in PT

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Abstract—PT X is an Indonesia leading company in ship repair field. With the growth of shipyard industries in Indonesia, company is expected to compete within tight competition. Problems arise when the reparation processes can't be finished on schedule. Respect to high vessel repairing demands, it can be a serious problem for company as they have many of ships waiting to be repaired. Management of technology might be the first step to solve the problem. Repair process within company is supported due to good management of technology policies. That's why technology assessment is necessary in this company. This research is proposed to be used as recommendation to PT X on how to measure and assess the technological capabilities of company. Technology Audit Model (TAM) is used as basic technology assessment model. While multi-hierarchical framework - Fuzzy Entropy Weight Approach (FEWA) are tools used to process the multi-criteria of assessment model. Based on the assessment, it can be known the weight and rank of all criteria, by which are be utilized as input for SWOT analysis. Based on this process, the the improvement strategies could be generated. The proposed strategies are knowledge sharing program, environmental impact evaluation, and project network.

Keywords—FEWA, MCDM, Multi-hierarchical Framework, SWOT, Technology Assessment, Technology Audit Model.

I. INTRODUCTION

INDONESIA is the world's largest archipelago. With the wealth and large coverage of sea, the investment and optimal exploitation of maritime sector in Indonesia can bring full advantages and support the country's economic growth. According to Peraturan Presiden (Perpres) Nomor 16/2017 about Indonesian maritime policies, Indonesia has aim to set the country as a maritime power in the world. One of five pillars of developing Indonesian maritime power is infrastructure and maritime connectivity development [1]. Indonesian National Ship-owners Association (INSA) stated that national shipyard industries have significant correlation toward maritime connectivity development in Indonesia, since shipyard industries give full support to sea transportation activity, with the power of vessel building and repair.

Shipyard industry basically runs in ship building and ship repair business. Most shipyards are concentrated along the coasts, like Surabaya, Jakarta, and Batam in Indonesia. In fact, shipyard market has high potential in Indonesia since there are many ship demands with various types from local and global markets over years. The need for the ship will continue to increase, so does the need of maintenance. Moreover

Indonesian government is intensively boosting the maritime sector. So the growth of shipyard industries in Indonesia is expected to increase this market related sector become more competitive.

PT X is an Indonesia leading company in ship repair and ship building field, with various types and sizes of ship ordered by clients around the world. This company experts in ship repair sector, with 4 floating dock in the shipyard. PT X focuses on ship repair activity rather than ship construction. In January until September 2017, there are 91 different vessels repaired in this company, compared to 10 ship built. This happens because according to the company, the repair activity bring more economic profit than building activity.

Problems arise when the reparation processes are expected to be completed on schedule. In fact, some of the reparation orders can't be finished on time. With high vessel repair demands, it can be a serious problem for company as they have many of ships waiting to be repaired. Moreover schedule accuracy are included in very important attribute for customer satisfaction [2]. Since time of completion is one of the important attribute to attract customers, company must find a way to overcome this difficulty especially for surviving the tight shipyard market competition in Indonesia.

Management of technology approach might be first step in solving the problem. Technology here embraces more than just machines since there are several technological entities besides hardware, including software, methods, systems, and human abilities employed in the creation of goods or services [3]. Management of technology needed as a tool used to manage the systems that enable creation, acquisition and exploitation of technology in a company, including shipyard industry. With a good management of technology policies in a company, it can accelerates the repair time of vessels. In reality, PT X still doesn't implement the proper management of technology policies yet. They don't know the right action to exploit and manage their various technologies as a way to meet their demand and run the business. Moreover they still can't identify and measure their technological position. The truth is if company can't measure their technology, they can't manage their technology properly. So, technology assessment is necessary in this company. Assessment provides a gap determination between the existing and the desired technological situation and, respectively, offers an evaluation about possibilities for upgrading technological capabilities.

Category	No	Criteria
1. Technology Environment	1.1.2	Technology innovation
	1.2.1	Involvement and participation
	1.2.2	Corporate strategy
	1.2.3	Goals
	1.3.1	Deployment
	1.3.2	Organizational chart
	1.3.3	Teamwork
	1.3.4	Structure
	1.4	Management of change
	1.5	Recruiting policies
2. Internal Technologies	2.1.1	Training
	2.1.2	Empowerment
	2.1.3	Reward system
	2.2	Internal technologies
	2.2.1	External technologies
	2.2.2	Basic technologies assessment
	2.2.3	Technology trends
	2.2.4	Innovation in marketing
	2.3.1	The product service concept
	2.3.2	Market assessment system
3. Markets and Competitors	3.1	Market and technology
	3.2	Business plan
	3.3	Building plan
	3.4	Intrepreneurship
	4	Entrepreneurship
	4.1	Science push
	4.2	Market pull
	4.3	Break-even time and break-even cost
	4.4	Full cost terms
	5	Functions
6. Acquisition and Exploration	6.1	Green products and processes
	6.2	After-life analysis
	6.1.1	Method of acquisition
	6.1.2	Capital investment
	6.2.1	Transfer procedures
	6.2.2	People transfer
	6.3	Exploitation for profit
	6.4	Protection

Technology Audit Model (TAM) can be used as technology assessment model. It is one of internal technology audit methods used in management of technology to identify and assess the strength and company’s technology position in business competition to take advantage and seek for opportunities from company’s capabilities [4]. Basically TAM focuses more in functionality of company in thoroughly not only in the technological hardware scope. Therefore it is suitable with the selected object since in this business, the critical things in doing reparation processes are not only related to technological scope but the interaction between the functional organization to support the activity. However, adjustment of this model is conducted to have better assessment model which is suitable with PT X business process, especially in ship repair process.

To support the implementation of many assessment criteria like that, can be used a multi-criteria decision making approach as the weighting or assessment tools. The assessment will be conducted internally with the help of internal experts from company. Fuzzy Entropy Weight Approach (FEWA) as MCDM tool is suitable for this kind of problem. This method is selected over other methods because of its simplified structure ease decision maker from complex analysis that are experienced using other weighting method, such as AHP or ANP [5]. With the combination of both method, FEWA is very powerful in facilitating many imprecise information and thought from expert judgements that come from different backgrounds of function to strengthen the assessment. Since there are so many criteria and hierarchies, multi-hierarchical framework analysis can be used as technology assessment framework because it can identify many criteria and categories based on their hierarchy level. Instead of common single framework, this framework can facilitates multi assessment level.

Based on the assessment result, the position and appropriate strategies for company can be generated using SWOT analysis method. Therefore this research is proposed to combine TAM criteria and multi-hierarchical framework - FEWA and give a recommendation to PT X as a shipyard company on how to measure and assess the technological capabilities of company.

II. RESEARCH METHODOLOGY

This research combines three methods, which are Technology Audit Model (TAM), multi-hierarchical framework - Fuzzy Entropy Weight Approach (FEWA), and SWOT analysis.

A. Technology Audit Model (TAM)

A technology audit tool called Technology Audit Model (TAM) which includes lot of areas to be considered in technology audit [4]. The purposes of TAM are to determine current technological status, to stress areas of opportunity, and to take advantage of the firm’s strong capabilities. TAM is a model consists of three level, with each level going deeper into more specific functions. There are six categories in the upper

level, 20 categories in second level, and 46 assessment elements in the third level. Lot of assessment level and component indicates how complete this assessment is for measuring firm’s complex processes. TAM scores using five-point scale for each assessment elements in third level. 5 is outstanding, 4 is very good, 3 is good, 2 is fair, and 1 is poor [6]. The ideal score is 5 and the avoided score is 1. (Table 1)

B. Multi-hierarchical framework - Fuzzy Entropy Weight Approach (FEWA)

Fuzzy Entropy Weight Approach (FEWA) is a tool used for evaluating and weighting the criteria. The speciality of this approach is the use of entropy weighting method together with fuzzy number. Fuzzy set theory is designed to deal with the extraction of the primary possible outcome from multiplicity of information that is expressed in vague and imprecise terms [7]. Fuzzy set theory treats vague data as probability distributions in terms of set membership, thus can be used in logical reasoning.

Fuzzy number set shape is varying, the common shape used is triangular fuzzy number. Triangular fuzzy numbers are utilized to consider the vagueness in human thoughts. In triangular fuzzy number, each element x in X to a real number in the interval $[0,1]$ is mapped into function $f_A(x)$ which represents the grade of membership of x in A . Then a fuzzy number A in real line R is a triangular fuzzy number if its membership function $f_A: R \rightarrow [0,1]$ is:

$$f_A(x) = \begin{cases} \frac{x-c}{a-c}, & c \leq x \leq a \\ \frac{x-b}{a-b}, & a \leq x \leq b \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

The graphical representation of this function can be seen in figure below. With $-\infty < c \leq a \leq b < \infty$, the triangular fuzzy number can be denoted by (c,a,b) .

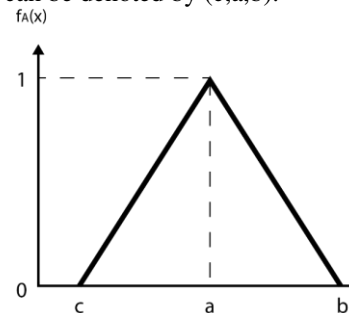


Figure 1. Triangular Fuzzy Number of (c,a,b)

While entropy concept was proposed by Shannon & Weaver in 1949. Since that, this method become well suited approach for measuring the relative contrast intensities of criteria to represent the average intrinsic information transmitted to the decision maker [8]. With score of hesitant fuzzy number, can be calculated the entropy value to obtain the weight of attributes. This combination approach can be called Fuzzy Entropy Weight Approach (FEWA), which is first proposed by Sun Qiaoping and Ouyang Jiewen in a research about energy police selection problem (2015).

FEWA method consist of three important steps which are

design of decision matrix, determination of entropy values and estimation of criterion weight. The procedures for FEWA are explained as follows[5]:

Step 1: Design of decision matrix.

Decision matrix is designed using linguistic terms. The five-scale linguistic expressions are employed to evaluate the criteria. They are characterized by triangular fuzzy numbers. (Table 2)

Table 2.
Linguistic Expression and Triangular Fuzzy Numbers

Linguistic values	Fuzzy number
Poor	(0, 0, 0.25)
Fair	(0, 0.25, 0.5)
Good	(0.25, 0.5, 0.75)
Very Good	(0.5, 0.75, 1)
Outstanding	(0.75, 1, 1)

The triangular fuzzy number above are translated into crisp values using Graded Mean Integration Representation (GMIR) method, used to solving the problem of defuzzification [9]. Let $X_{ij} = (c_{ij}, a_{ij}, b_{ij})$; $i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$; to be the triangular fuzzy number. By the GMIR method, the GMIR $R(X_{ij})$ of X_{ij} is:

$$R(X_{ij}) = \frac{c_{ij} + 4a_{ij} + b_{ij}}{6} \tag{2}$$

After that, normalization of initial crisp values is conducted. The $R(X_{ij})$ value is subtracted with the maximum value given for each decision maker [41]. The formula is:

$$S(X_{ij}) = R(X_{ij}) - R(X_i)_{max} \tag{3}$$

Then the entropy values for the sub-criteria are determined by first normalising the information a hesitant decision to obtain the normalized score matrix \tilde{s} using formula of:

$$\tilde{s}_{ij} = \frac{s(X_{ij})}{\sum_j^m s(X_{ij})} ; \text{ where } 0 \leq \tilde{s}_{ij} \leq 1 \tag{4}$$

Step 2: Determination of entropy values

The normalized values are used to determine the entropy values for the various criteria using calculation of:

$$E_j = -\frac{1}{\ln n} \sum_{i=1}^n \tilde{s}_{ij} \ln \tilde{s}_{ij} ; \text{ where } 0 \leq E_j \leq 1 \tag{5}$$

Step 3: Estimation of criterion weight.

First the total entropy value can be computed as:

$$E = \sum_{j=1}^m E_j \tag{6}$$

Based on the entropy values for criteria, the weight for each criteria is estimated by:

$$W_{ij} = \frac{1 - E_{ij}}{n - E} \tag{7}$$

$$\text{where } 0 \leq W_{ij} \leq 1 \text{ and } \sum_{j=1}^n W_{ij} = 1$$

FEWA method fits with multi-hierarchical framework. Basically the purpose of this framework is to generate more options for the company using the advantages of multi-hierarchical framework.

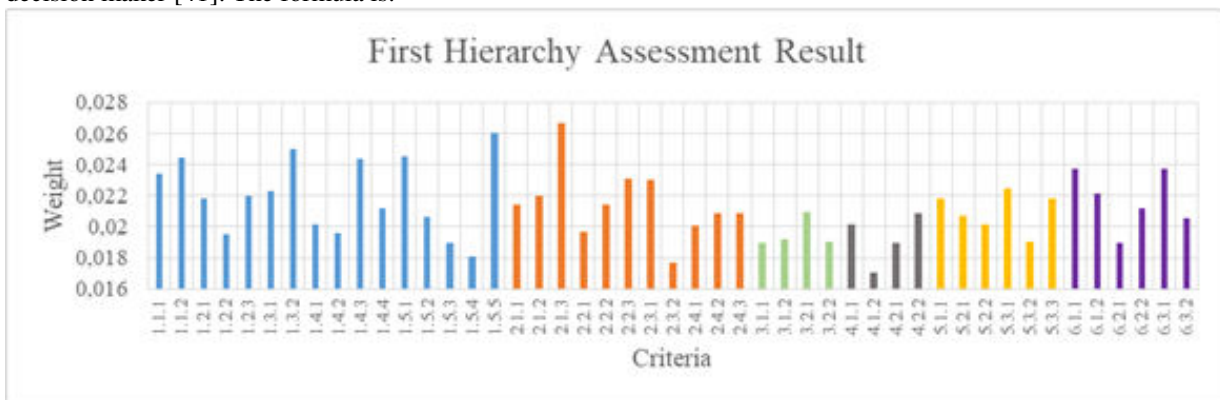


Figure 2. Weight Assessment of First Hierarchy Criteria.

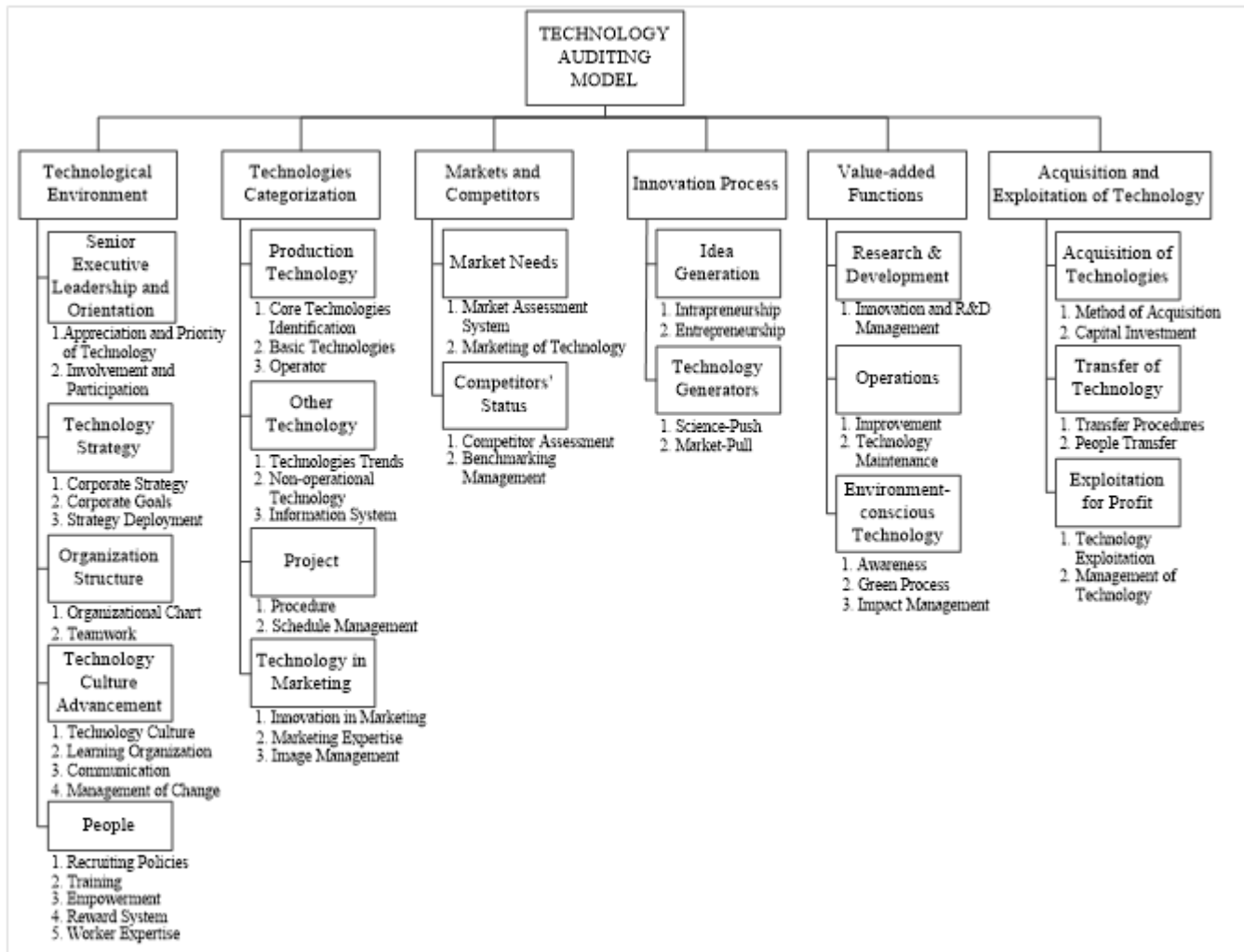


Figure 3. Technology Auditing Model Criteria Framework.

A. SWOT Analysis

Strengths, weaknesses, opportunities, and threats (SWOT) analysis is a method used by a firm to evaluate their strengths, weaknesses, opportunities, and threats involved in business process. With this framework of SWOT, company can analyze their business process, identify the potential or existing problems then develop improvement strategies. SWOT is a basic model for assesses what a business can and can't do, as well as its potential opportunities and threats. With SWOT method, the obtained information separated into internal factor (strengths and weaknesses) and external factors (opportunities and threats).

III. RESULT AND ANALYSIS

After the observation, data collection, and data processing, and the results are obtained as follows.

A. TAM Criteria and Framework Identification

TAM model is already proved to be match with PT X business process in general. However, detail adjustment is needed because not all of the sub-component is suitable with this company. The new TAM model has 47 assessment

Table 3. SWOT Factors

STRENGTH		WEAKNESS	
S1	Good expertise of worker on ship repair process	W1	The ship repair process is often late from schedule
S2	Teamwork culture within company is high	W2	Lack of innovation management for employees
S3	Good recruiting policies	W3	Bad reward system for employees
S4	Good information system to support business process	W4	Market assessment system is not good enough
S5	Good SOP of company and its actualization	W5	Empowerment management is not good enough
S6	The company has good awareness of the environment	W6	The technology transfer procedure has not done well
S7	The technology in the company has been optimally exploited	W7	Bad environment management system in ship repair process
OPPORTUNITY		THREAT	
O1	Government policies that support and boost shipyard industries in Indonesia	T1	Raw material costs tend to rise
O2	The ship regulation for docking periodically	T2	High competition for shipyard industry
O3	Growth of inter-island sea transportation demand	T3	Weak domestic industries supporting the supply of materials and components
O4	Cooperation program between SOEs	T4	Different tax incentives for the shipyard industries outside Batam
O5	Macroeconomic stability with relatively good inflation rate	T5	Limited access to capital investment and working capital

criteria, 19 sub-categories, and 6 main categories.

All of those criteria are grouped into multi-hierarchical framework with 3 level of hierarchy. First level is using all of the 47 criteria as one weighting model. Second level is using all of criteria within each categories to generate weight score. So there will be six different weight score models, according to different categories. Third level of hierarchy framework is using all of criteria within each sub-categories to generate weight score. So there will be 19 different weight score models according to number of sub-categories in the auditing model. The full framework can be seen in Figure 3.

B. Fuzzy Entropy Weight Approach

FEWA method is used to weight 47 different criteria from proposed technology auditing model to generate technology assessment score. There are 7 experts from different functions within company. The result of first level hierarchy assessment can be seen in Figure 2. From the result, can be seen that the criteria with highest rank is operator criteria (weight of 0.0266) included in second category. While the lowest rank is entrepreneurship criteria (weight of 0.017) included in fourth category. While the category with highest rank (biggest average weight) is technological environment category. While the lowest rank is innovation process category. Technologies categorization is the third highest rank although one of its criteria meets the highest rank against all criteria. Assessment for other hierarchy level also conducted to have multi-preferences.

C. SWOT Analysis

The internal factors of SWOT are obtained from the previous assessment using FEWA method on technology auditing model criteria. While the external factors of SWOT are obtained from the interview and discussion with internal expert of company. The following is the recapitulation table of identified internal factors (strengths and weaknesses) and external factors (opportunities and threats) of PT X. (Table 3)

After that factor evaluation is conducted for both internal and external factors to know the position of company based on SWOT map result. The result of Internal Factor Evaluation (IFE) is 0.986, while the result of External Factor Evaluation (EFE) is 1.381. Therefore, the position of company is located at first quadrant. The strength's score is more dominant than weakness, while the opportunity's score is more dominant than threat. So the appropriate strategy for PT X according to the SWOT method result is aggressive strategy, which is using firm's internal strengths to take advantage of external opportunities.

Therefore based on the identified SWOT matrix strategies, the proposed improvement strategies for PT X are develop knowledge management strategy, develop new production competences of company, develop environment management system within company, develop good schedule management strategy, increase the cooperation with SOEs as value-added for company, and develop good maintenance strategy.

IV. CONCLUSIONS

The following are the conclusions obtained from this research.

1. The assessment model consists of three hierarchy level with 47 criteria of technology assessment in total. They have already adjusted to fit the company business process.
2. The assessment process is assisted by 7 internal experts of company. FEWA method is used for three different hierarchy level. In first level assessment, criteria with highest rank is operator criteria, while the lowest rank is entrepreneurship criteria. In second level assessment, there are 6 different models according to categories. In third level assessment, there are 19 different models according to sub-categories.
3. In SWOT analysis, the factor identification is conducted using assessment result for internal factor and discussion with company for external factor. From Internal Factor Evaluation (IFE) process, the differences between strength and weakness score is 0.986. From External Factor Evaluation (EFE) process, the differences between opportunity and threat score is 0.533. Using SWOT map, the position of company is located in first quadrant. So the appropriate strategy for company according to SWOT result is aggressive strategy, which is using firm's internal strengths to take advantage of external opportunities.
4. There are six improvement strategies proposed for company. They are develop knowledge management strategy, develop new production competences of company, develop environment management system within company, develop good schedule management strategy, increase the cooperation with SOEs as value-added for company, and develop good maintenance strategy.

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