Measuring Industrial Resiliency by Using Data Envelopment Analysis Approach

Ida Bagus Made Putra Jandhana*, Teuku Yuri M. Zagloel, Rahmat Nurcahyo

Abstract: Having several economic crises that affect industrial sector performance in the past decades, decision makers should consider to utilize an application that enables them to measure industrial resiliency more precisely. This research contributes not only a framework for the devel-opment of resilience measurement application, but also several theories for the concept building blocks, such as performance measurement management, and resilience engineering in real world environment. The data evaluated in this paper was taken from the metal industry sector from Statistics Indonesia. The sectoral efficiency was measured by using Data Envelopment Analysis in series. The result shows that there were sectoral efficiency drops when currency exchange shocks occur. This research is a continuation of previously published paper on performance measurement in the industrial sector. Finally, this paper contributes an alternative performance measurement method in indus-trial sector based on resilience concept. Moreover,this research demonstrates how applicable the concept of Resilience Engineering is and its method of measurement..

Index Terms: Resilience, Measurement, Data Envelopment Analysis, Sector, Industrial,

I. INTRODUCTION

The global industrial sector has been pressed to develop strategies that enable them to sustain and adapt to the various business environment dynamic changes. Those challenges come from global competition, technological advancements, interconnectivity and economic liberalization [1, 2]. Additionally, these dynamic changes create additional risks not only in manufacturing sector, but also in business environment due to the volatility of raw material acquisition costs, volatility of exchange rate, drop of global market and other causes. Various global crises have shown that the traditional methods of measurement for both firms' and sectors' performance will not be able to assess the conditions more precisely [3]. To overcome those challenges, corporate capabilities, which consist of the level of innovation, entrepreneurship, human capital, potential market, and business strategy, will determine the survivability and competitiveness of all businesses in a global rapid changing environment [4]. Together with corporates' ability to measure the current industrial sector performance, evaluate various alternative strategies, and selecting the right strategy that enables industrial sector to boost its performance level during economic crises, these capabilities define industrial sector strength [9].

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Based on this thought, this research promotes an efficiency based framework of measuring method by using Data Envelopment Analysis (DEA). Additionally, from this concept, the research proposes a framework to develop tool that enables decision makers to measure and assess the industrial resiliency within a country. To elaborate the development process and framework of measurement, this paper explains building block of knowledge, experimental details, result and discussion, and conclusion. This paper also complements previous published papers on similar topic, such as the review of various competitiveness indices [3], the emerging issues on Performance Measurement and Management related to risk management [7], and research agenda on integrating Resilience Engineering with different theories and settings [8].

To facilitate the study, there are several theories that become the building block of the industrial resiliency measurements. Those theories were drawn from the following literature topics:

1.1 Performance Measurement and Management

There has been an attention toward the applications of Performance Measurement and Management in industrial development, both at firm level and sector level, for more than 20 years. The field of performance measurement and management contains two aspects. The first aspect is associated with the measurement that defines the quantifying process of efficiency and effectiveness of an action [10]. Performance measurement is more focus on development metrics that enable an organization to evaluate and determine its performance [11]. The second is the management aspect, which relates to the process of aligning manager performance to both functional and corporate strategies. Performance management is considered as a management tool for improving organization performance [12]. Most of the applications are directed toward measuring financial measurement and management [7]. As stated previously, the development and implementation of performance measurement and management in manufacturing sector become more challenging as there are dynamic changes in the global manufacturing sector. These challenges come from the facts that today's manufacturing firms not only contain production facilities, but also various services associated with products' deliveries, costs, and qualities to the end users [13]. This condition demands different performance measurement approach in accounting measures, variance reports, risk measurement and management, and so on.

1.2 Resilience Engineering (RE)

Resilience Engineering (RE) is a proactive approach that fosters the capability of an organization or a system to respond to the changed condition and rectify the impact of the changes back to a normal state [5]. Therefore, resilience is defined as the capability of systems or organizations to anticipate and adapt to any potential risk of having failure [6]. Today, as the understanding of the importance of risk management increases, the field of RE gets more attention in the study of risks under Complex Socio-Technical Systems (CSSs) [8]. RE is a relatively new discipline that studies failures in complex systems, risk management, and the capacity to adapt in uncertain condition. RE defines ways to understand the possibility of economic or financial loss or gains, physical damage, injury, or delay as a consequence of the uncertainty associated with pursuing a course of action [14]. Under RE, building resilience measurement will be closely related to three main activities in risk management: risk identification, risk analysis, and risk responses [15]. By understanding and applying proper risk management, decision makers can develop a more robust and reliable business strategy and plan.

Under industrial operation or process scheme, one needs to consider riks in three operational states: normal, upset and catastrophic [16]. By understanding these states and manipulating various operation variables, management team should be able to mitigate any possible risks and maintain the system to operate under normal state. A system with normal state will turn to be upset when the abnormality is not rectified immediatly and the system return back to normal status. Further, the upset state will turn to become catastrophic state when the effort to rectify the abnormality fails. In this research, RE concept applied should exhibitits role in establishing the system capability to rectify its state from upset or catastrophy back to a normal state [5]. By conducting resilience measures within an organization or system, a management team will become more capable in maintaining normal process, more adaptable to new environment, and faster recovery from any upset or catastrophy states.

As stated previously, this study focuses on developing methods that will be applied for measuring resilience by calculating industrial sector's efficiency [17]. Industrial sector is on meso level among three levels of Economics [18]. Those three levels are:

a) Microeconomic Level that studies the economic behavior of individual businesses or households,

b) Mesoeconomic Level that analyzes the economic individual industrial sector or market, and

c) Macroeconomic Level that studies the cumulative capacity of all economic entities that form building blocks.

To generate the output at mesoeconomic level, Gross Domestic Product (GDP) of industrial sector, there are inputs that will be used such as human resource expenses, material expenses, energy expenses.

1.3 Data Envelopment Analysis (DEA)

DEA is a non-parametric method based on a linear programing method. This method is used to estimate production frontier by measuring the efficiency from one Decision Making Unit (DMU) to another DMU. The efficiency measurement is an important step toward resiliency measurement. The efficiency will be valued between 0 to 1 (perfect efficient). To improve firm resiliency, management will maximize their ouput when possible [22]. On country level, resiliency will be determined not only by efficiency, but also by information transparancy [23]. Other than efficiency, resilience will also be measured through its predictability and time lapse needed to rectify its abnormal state to normal state. This measurement also defines the quality of engineering design [24].

Efficiency also relates to system or organization performance since it measures the ratio between output and input [18]. Furthermore, there are three factors that create efficiency:

a) Same level of input produces bigger output,

b) Smaller input produces the same level of output, and

c) Bigger input produces a much bigger output.

Additionally, based on the literature study, there are two DEA models for performance measurement: Charnes, Cooper, and Rhodes (CCR) and Banker Charnes and Cooper (BCC) [28]. CCR, the basic model of DEA, is also known as the Constant Return to Scale (CRS), measures overall technical efficiency under a constant ratio between output dan input when DMUs operate optimally in a perfect competition. Another DEA model that allows for the variability in return is called BBC or Variabel Return to Scale (VRS). Unlike CRS, this approach allows the efficiency calculation of DMUs that operate sub-optimally in imperfect competition.

Measuring resiliency by DEA approach is not new. For example, DEA approach is used to measure resiliency through how efficient a management team is in a petrochemical plant in responding to a crisis or emergency [5]. DEA approach was also used to measure the short-term resilience of individual farms in the agricultural areas of Spain [25] and the sustainability of human development in a country [26]. DEA was employed to measure the relationship between microeconomic market efficiency and economic resiliency during crises. United Nations adopts the concept of efficiency measurement in assessing resilience measurement of a town. By calculating the efficiency of resource usage, such as water, energy, foods, and other, the town resiliency can be calculated and improved [27]. All of these studies conclude that the operational efficiency reflects the resiliency of an object.

II. MATERIALS AND METHODS

As explained earlier, the resilience in industrial sector is calculated through its technical efficiency based on the amount of input and output (Input-Oriented Measures). This efficiency is measured by Decision Making Units (DMU) that represents the sector's output by using a minimal amount of input employed in the sector. This can be formulated by the general efficiency formula, as follows [28]:

$$Efficiency = \frac{Weighted\ Total\ Input}{Weighted\ Total\ Output}$$

If there are n DMUs with m input and s output on each DMU, then relative efficiency score for DMU p would be explained as follows [29]:

$$\max \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \qquad (1)$$

$$v_k, u_j \geq 0$$

$$s.t \quad \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \quad \forall i \qquad (2)$$

$$\forall k, j$$

Where k = 1 to s, j = 1 to m, for any value of i = 1 to n, yki = the amount of output k produced by DMUi, Xji = the amount of input j utilized by DMUi, Vk = weight of ouput k, uj = weight of input j.

From equation (1) and (2), each of n DMUs is constructed in linear form as:

$$\max \sum_{k=1}^{s} v_k y_{kp} \qquad (3)$$

$$s.t \sum_{j=1}^{m} u_j x_{jp} = 1 \qquad (4)$$

$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leq 0 \ \forall i \qquad (5)$$

$$v_k, u_j \geq 0 \ \ \forall k, j$$

The measurement will be made up from five dimensions. Further, each dimension contains several variables. All of the variables go through validity and reliability test to ensure their validity in forming any dimensions. Moreover, the variables and dimensions involved in the production process are selected based on the factors suggested by literature studies on Production Theory [19]. These factors, mainly comprise of human resource, other resources as input, capital, and technology, are translated into five dimensions that are independent from one to another. However, these dimensions are integrated to form the resilience state of industrial sector. Further, the variables that shape up the measurement will be refered similarly to those variables measured in Global Competitiveness Index (GCI) developed by Institute for Management Development [20] and World Economic Forum [21].

For data consistency of the sector level and model validation, the input data for measurement came from annual survey data conducted by Statistics Indonesia from 2005 to 2015. The survey covered 1.296 both medium and large metal industries in Indonesia during that period [30]. Then, the data were grouped into 1 output and 3 inputs for measurement. The output data were taken from global industrial incomes which include the income of industrial goods, the income of service industries, the profit/loss of good sold, the income from building and machinery rent, the income from salvage goods and wastes, the income electric power sold, and the difference of the inventory of semi-finish goods. The input data consist of: the values of raw material and its additive material in use (input 1), the values of labor and electricity expenses (input 2), and the values of fuel and its additive expenses (input 3). By calculating these data through DEA method and plotting the efficiency values annually.

III. RESULTS AND DISCUSSION

The global crises affected the local firms' productivity in Indonesia [31]. The subprime mortgage crisis that started in 2007 in the USA was followed by the global financial crisis in 2008. Based on the result shown on the following Figure 1, it can also be examined that there are efficiency drops on 2009 and 2014. As a result, many companies that include Indonesian companies were having limited access to capital and bank credit needed. This condition caused the raising cost of external financing which affects the industrial sector in the country. By having limited financial capability, the local companies were not able to maintain growth. Some companies with financial constrain cut their spending to protect their liquidity. In other cases, the companies were willing to sell their assests to maintain their operation. During crises, having intra-link to Foreign Direct Investment (FDI), local firms could improve their productivity and resilience [31].

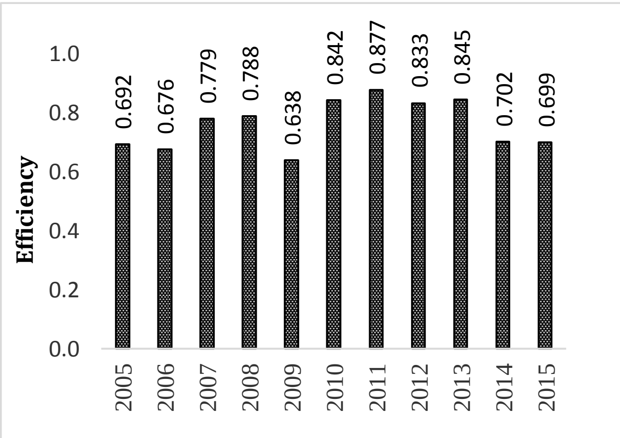

Figure 1. The Annual Efficiency of Metal Processing Industries in Indonesia.

As indicated on Figure 1, the 2008 global financial crisis had affected the industrial sector. The impact is shown in 2009 data, the industrial efficiency plunged from 0.788 in 2008 to 0.638 in 2009. The result was also reflected in the GDP generated from metal industries in 2009 that had a negative growth of - 4.26%. Generally, this value was worse than the GDP growth of manufacturing sector that still grew 2.21% in 2009. However, this growth was still lower compare to the growth achieven in 2008. The following Figure 2 shows the comparison of GDP growth among metal industries and manufacturing sector in general. Inspite of the drop in 2009, the GDP of metal industries was able to accelerate faster in 2010.

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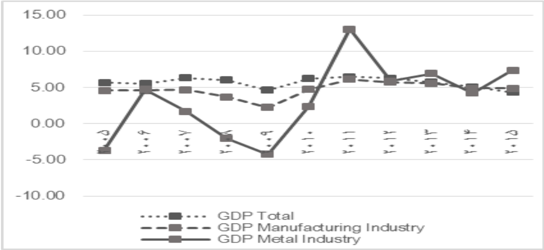

Figure 2. Growth of GDP Indonesia, The Manufacturing Industry GDP, and The Metal Processing Industry GDP, 2015-2016 [30].

In 2014, the Indonesia currency, Rupiah, depreciated from Rp 9,700/US Dollar by the middle of 2013 to Rp 12,400/US Dollar [36]. This shock caused an increase in, not only the cost of import product, but also the cost of financial borrowing from foreign financial institutions. Cost of production also increased due to the increase of electricity tarrifs in 2013 as government reduce energy subsidies for both industrial sector, government, and household consumption. In this circumstance, again, cost of financial borrowing in US Dollar increased dramatically. This would not only increase the cost of operation, but also prevent these companies from expanding their operation further to generate more output. Furthermore, the increase of electricity cost pressed the industrial sector capability to produce more outputs.

Based on the previous Figure 1, the result also suggests that the drop of Rupiah to the US Dollar had a much weaker impact to the efficiency in the sector in 2015 compare to the impact in 2008. In other words, the sectoral efficiency in 2014 was relatively similar to the sectoral efficiency in 2015. Therefore, the result concludes that global crisis affects the industrial sector's efficiency significantly. Finally, both 2008 and 2014 crises show how important the implementation of risk management is in the industrial sector. One of the measures is by improving industrial resilience through analizing the effect of financial flexibility to the cost of external financing.

Based on the result, this research confirms that the knowledge described previously can become a starting point for further studies in Resilience Measurement. In this study, the knowledge provides a path for the application developments of resilience measurement that based on the standard of application design and development set in Software Engineering (SE) [13]. By using SE approach the knowledge of resilience, along with its problems, will be explored further through several process, such as framing, representing, and transforming, and using other problem solving processes to meet recognized need [11]. This theory was developed around Rogers' notion that engineering approach enables people to solve problems given a real world environment and need. Later, this concept will be applied in designing and constructing any applications with certain design requirements and specifications [12]. The followings are the guidelines from Software Engineering [13], such as:

a) Design and development planning,
b) Design and development inputs,
c) Design and development outputs,
d) Design and development review,
e) Design and development verification,
f) Design and development validation, and
g) Control of design and development changes.

Other than employing the design and development of application guidelines, the development of framework and concept of the Industrial Resilience measurement should also refer to the engineering approach [14].

Despite the foreseeable benefits of utilising resiliency measurement frameworks, there are some precautions that need to be addressed. For future reference, the followings are some hurdles that should be anticipated by decision makers in applying the frameworks:

a) Resiliency measurement is still a relatively new field, so it needs more studies toward concept and measurement method development [8].
b) Generally, here is still lack of cohesiveness in the body of knowledge of performance measurement created by different fields of studies.
c) There are unique knowledge and processes on each field of industry that demand a specific study to cover its complexity in both object observation and the design of measurement system [10].

There are indications that many of the components in resilience measurement are not important in assessing individual business' or industrial sectors' recovery process [18].

I. CONCLUSION

The implementation of performance measurement in both firm and sector level significantly promote the awareness of capability and risk associated with the operation. It plays a key role in developing strategies, communication among stake holders, and management process integration. As discussed earlier, in general, there has been a lack of cohesiveness in the field of performance measurement, especially in resiliency measurement in the industrial sector. Additionally, resiliency measurement in industrial sector needs further specific studies due to its characters that are dynamic, complex and unique. This research proposes a framework for the application development that enables decision makers to measure and assess industrial resiliency. As shown in the explanation, industrial resilience can be traced through how efficient the industrial sector that includes the metal industries. Furthermore, DEA method provides an adequate tool for efficiency measurement in industrial sector. For the future agenda, there should be researches not only in developing application that assist the measurement of industrial resilience but also in developing resilience concept and measurement in other industrial sub-sectors. Although this research proposes the approach of developing an measurement tool in industrial resilience based on the data gathered from metal processing sector in Indonesia, the tool can be used in developing similar tools to measure resilience in other industries as well. In the future, there should be an effort to develop a more integrated tool that is capable to measure and analyze various challenges in industrial sector, such as level of innovation, entrepreneurship, human capital, potential market, and business strategy will determine the survivability and competitiveness of all businesses in global rapid changing environment.

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REFERENCES

1. Liu, L., & Jiang, Z. (2016). Influence of technological innovation capabilities on product competitiveness. Industrial Management & Data Systems, 116(5), 883-902.
2. Choon Tan, K., Kannan, V. R., Handfield, R. B., & Ghosh, S. (2000). Quality, manufacturing strategy, and global competition: An empirical analysis.Benchmarking: An International Journal, 7(3), 174-182.
3. Zagloel, Y., & Jandhana, I. B. M. P. (2016). Literature Review of Industrial Competitiveness Index: Research Gap.
4. Agus, A. A., Isa, M., Farid, M. F., &Permono, S. P. (2015). An assessment of SME competitiveness in Indonesia. Journal of Competitiveness, 7(2).
5. Azadeh, A., Salehi, V., Ashjari, B., &Saberi, M. (2014). Performance evaluation of integrated resilience engineering factors by data envelopment analysis: The case of a petrochemical plant. Process Safety and Environmental Protection, 92(3), 231-241.
6. Hollnagel, E., Woods, D. D., & Leveson, N. (2007). Resilience engineering: Concepts and precepts. Ashgate Publishing, Ltd..
7. Taticchi, P., Tonelli, F., & Cagnazzo, L. (2010). Performance measurement and management: a literature review and a research agenda. Measuring business excellence, 14(1), 4-18.
8. Righi, A. W., Saurin, T. A., & Wachs, P. (2015). A systematic literature review of resilience engineering: Research areas and a research agenda proposal. Reliability Engineering & System Safety, 141, 142-152.
9. Nurcahyo, R., &Wibowo, A. D. (2015). Manufacturing Capability, Manufacturing Strategy and Performance of Indonesia Automotive Component Manufacturer. Procedia CIRP, 26, 653-657.
10. Neely, A., Gregory, M., & Platts, K. (2005). Performance measurement system design: A literature review and research agenda. International journal of operations & production management, 25(12), 1228-1263.
11. Bititci, U. S., Turner, U., & Begemann, C. (2000). Dynamics of performance measurement systems. International Journal of Operations & Production Management, 20(6), 692-704.
12. Rogers, G. F. C. (1983). The Nature of Engineering a Philosophy of Technology. Palgrave Macmillan.
13. Fowler, J. W., & Rose, O. (2004). Grand challenges in modeling and simulation of complex manufacturing systems. Simulation, 80(9), 469-476.
14. Chapman, C. B., & Cooper, D. F. (1983). Risk engineering: basic controlled interval and memory models. Journal of the Operational Research Society, 51-60.
15. Dey, P. K., Kinch, J., & Ogunlana, S. O. (2007). Managing risk in application development projects: A case study. Industrial Management & Data Systems, 107(2), 284.
16. Dinh, L. T. T., et al. (2012). "Resilience engineering of industrial processes: Principles and contributing factors." Journal of Loss Prevention in the Process Industries25(2): 233-241.
17. Wreathall, J. (2006). Developing models for measuring resilience. John Wreathall & Co., Inc., Dublin, Ohio.
18. Rose, A., & Krausmann, E. (2013). An economic framework for the development of a resilience index for business recovery. International Journal of Disaster Risk Reduction, 5, 73-83.
19. Pindyck, Robert S and Daniel L. Rubienfield. (2005). Microeconomics Sixth Edition. Pearson Prentice Hall, New Jersey
20. IMD, I. (2012). World Competitiveness Yearbook. International Institute for Management Development, Lausanne.
21. Schwabb, Klaus (2013). Global Economic Report. World Economic Forum. Geneva. Switzerland.
22. Allen, Karen Lynn. (2016). Efficiency Is Not the Enemy of Resiliency. http://www.resilience.org/stories/2016-03-07
23. Howell, Lee. (2013). Resilience: What It is and Why It's Needed. www.pwc.com.
24. Holling, C.S. (1996) Engineering Resilience versus Ecological Resilience, in: P.C. Schulze (Ed.) Engineering Within Ecological Constraints, pp. 31 – 44 (Washington, DC, National Academy Press).
25. Reig-Martínez, E., &Picazo-Tadeo, A. J. (2004). Analysing farming systems with Data Envelopment Analysis: citrus farming in Spain. Agricultural Systems, 82(1), 17-30.
26. Blancard, S., &Hoarau, J. F. (2013). A new sustainable human development indicator for small island developing states: A reappraisal from data envelopment analysis. Economic Modelling, 30, 623-635.
27. United Nations. (2017). Resilience and Resource Efficiency in Cities. United Nations Environment Programs.
28. Wen, M. (2015). Uncertain data envelopment analysis. Springer.
29. Charnes, A., Cooper, W. W., Lewin, A. Y., Morey, R. C., & Rousseau, J. (1984). Sensitivity and stability analysis in DEA. Annals of Operations Research, 2(1), 139-156.
30. Statistics Indonesia (2017), https://www.bps.go.id/
31. Negara, S. D., & Adam, L. (2012). Foreign direct investment and firms' productivity level: lesson learned from Indonesia. ASEAN Economic Bulletin, 29(2), 116-127.