Technology Adoption Segmentation of MSMEs in Border Areas Using TRI and Hierarchical Clustering

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***Abstract*— Micro, Small, and Medium Enterprises (MSMEs) in border areas such as Nunukan-Sebatik often face challenges in adopting modern technologies, which hinder their growth and competitiveness. This study employs a segmentation approach using agglomerative hierarchical clustering based on the Technology Readiness Index (TRI) to segment MSMEs in border areas and develop targeted strategies to accelerate technology adoption. A hierarchical clustering technique is applied to segment MSMEs according to their technology readiness levels. Data on technology readiness were collected through surveys, and the clustering results were analyzed to identify distinct MSME groups. The TRI score was 3.72, indicating a high level of technology readiness, which suggests that many MSMEs are open to technological innovation into their daily operations. The results also reveal that MSMEs in Nunukan-Sebatik can be grouped into two clusters based on hierarchical clustering: Cluster 1, which consists of MSMEs that are more prepared and optimistic about technology adoption, and Cluster 2, which faces significant challenges. These findings highlight a digital readiness gap among MSMEs, where only a tiny portion (Cluster 1) is fully prepared, while the majority (Cluster 2) still encounters barriers to adoption.**

Keywords*— Border Areas, Clustering, MSME, Technology Readiness

I. Introduction

Indonesia relies heavily on micro, small, and medium enterprises (MSMEs) as a key driver of its economic growth, similar to many other countries. In border areas such as Nunukan-Sebatik, MSMEs play an important role as drivers of the local economy. MSMEs in border areas face challenges in adopting digital technology, mainly due to limited infrastructure, uneven internet access, and low digital literacy [1], [2]. The Sustainable Development Goals (SDGs) highlight the essential contribution of MSMEs in promoting sustainable development and advancing national progress. [3], [4].

Digital technology adoption can provide significant benefits such as operational efficiency, better access to information, improved communication, and transformation of business models, it also presents challenges, including technological uncertainty, high implementation costs, and social barriers that must be addressed [5].

The adoption of digital technology by MSMEs in a country's border areas offers excellent opportunities to overcome geographical limitations and increase competitiveness [2], [6], [7]. In areas such as Nunukan-Sebatik, which directly borders neighboring countries, digitalization also has the potential to increase cross-border connectivity and integrate local MSMEs into the global economic ecosystem. However, this effort requires a deep understanding of the readiness of MSMEs to adopt technology in the region so that it can be carried out effectively and sustainably. Therefore, it is necessary to measure the level of readiness of MSMEs in the border area to adopt digital technology.

The Technology Readiness Index (TRI) is an essential tool for measuring the readiness of MSME technology to adopt digital innovation [8], [9], [10]. Understanding this level of preparedness can help design more appropriate strategies for encouraging the digitalization of the MSME sector on the border. Several previous studies have applied TRI to measure MSME digital readiness. Study [11] developed 21 indicators to assess MSMEs' readiness for digital marketing. Study [12] used TRI to evaluate e-commerce adoption, highlighting that optimism, innovativeness, and competitive pressure significantly influence customer readiness and IT adoption. A Study [13] found that both technological and managerial readiness based on the Technology Organization Environment (TOE) and TRI frameworks significantly impact the use of Industry 4.0 technologies, with differing effects between micro and small-medium enterprises in Karawang.

Further research on the results of TRI measurements can still be done, including by segmenting MSMEs based on the TRI results that have been obtained. A preliminary literature search revealed limited publications addressing TRI based segmentation within border areas. Various methods can be used in segmentation, one of which is the clustering technique, which is one of the techniques in machine learning, namely unsupervised learning [14], [15], [16].

The Agglomerative Hierarchical Clustering (AHC) method will be used in this study. Unlike other clustering methods, AHC can form a hierarchical structure that is easier to interpret

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[17], [18], to reveal a more precise pattern of readiness to adopt digital technology. Studies on applying Agglomerative Hierarchical Clustering (AHC) have shown diverse and impactful use cases. Study [19] utilizes AHC to group tweets about the presidential election into 10 clusters based on content types and user emotions during the 2024 presidential election. Study [20] applies hierarchical clustering to segment mall customers based on demographic and behavioral attributes in the retail sector. Meanwhile, Study [21] implements AHC to classify junior high school students according to their interests and academic abilities, aiming to assist in selecting appropriate high school majors, and successfully develops a prototype application to visualize the classification results.

This study aims to identify the segmentation of MSMEs in border areas based on their level of digital readiness using the Agglomerative Hierarchical Clustering approach on the Technology Readiness Index (TRI). By conducting segmentation, this study is expected to provide insight into the pattern of MSME digital readiness and the factors that differentiate each segment. The results of this analysis can be the basis for policymakers and stakeholders to design more targeted strategies to encourage the adoption of digital technology among MSMEs in border areas. In addition, this study also contributes to enriching the literature related to the segmentation of MSME digital readiness, especially in border areas with unique challenges and characteristics in the digital transformation process.

II. METHODOLOGY

This research was conducted through several systematic stages to analyze the segmentation of MSMEs in border regions based on the Technology Readiness Index (TRI) using Agglomerative Hierarchical Clustering. The stages of the research are outlined in Figure 1.

Based on Figure 1, there are several main stages in this study. The first stage is to identify the problem and research objectives. This initial stage involves identifying the main issues MSMEs face in border areas when adopting digital technology. Furthermore, the research objectives are determined to group MSMEs based on their technological readiness using the clustering method, followed by the questionnaire and data collection preparation. The questionnaire was designed using the Technology Readiness Index (TRI) model by Parasuraman, encompassing four key dimensions: Optimism, Innovativeness, Discomfort, and Insecurity [10]. Each dimension is represented by three indicators, resulting in a total of 12 questionnaire items. Respondents were asked to indicate their agreement with each statement using a 5-point Likert scale.

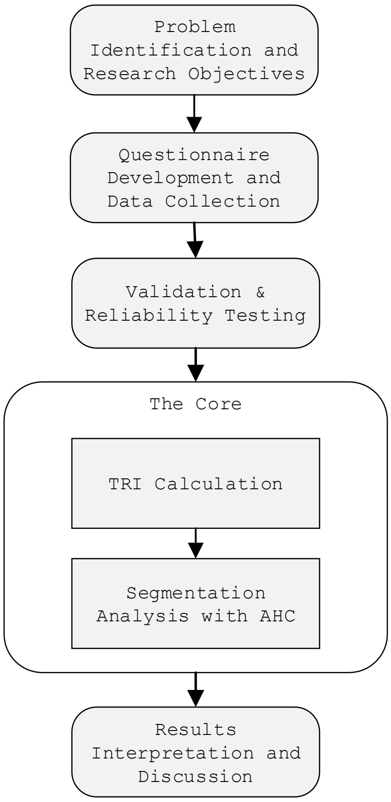

Figure 1. Research Stages

Data collection was carried out through a survey targeting MSMEs located in border regions. The complete list of items used in the questionnaire is presented below:

Optimism
OPT1: Digital technology can improve the efficiency of my MSME business in this border area
OPT2: I think that adopting technology can help my MSME to reach a wider market
OPT3: I am optimistic that new technology will help in my business management

Innovativeness
INNO1: I am interested in trying new digital apps or devices for my MSME
INNO2: I am ready to learn and use new technologies for the advancement of my business on the border
INNO3: I am excited about the idea of adopting modern technology in MSME operations

Discomfort
DIS1: I am worried that digital technology is too complicated for me to understand and use
DIS2: Relying on technology for my business makes me feel uncomfortable
DIS3: I prefer to stick to traditional methods to run my SME

Insecurity
INS1: I am concerned that by using digital technology, my business data could be misused
INS2: I am hesitant to adopt technology because of information

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security and online transactions
INS3: Using digital technology makes me worried about potential fraud or digital crime.

The subsequent step involves testing the questionnaire through Validity and Reliability assessments. Prior to data analysis, these tests are conducted to confirm that the questionnaire's measurement instruments yield consistent and accurate outcomes. The Validity Test is performed by correlating each item's score with the total score, ensuring that every question effectively captures the intended construct. Meanwhile, the Reliability Test is conducted by calculating the Cronbach's Alpha value to evaluate the internal consistency of the instrument.

The core stage is first entered by calculating the Technology Readiness Index (TRI). The testing process for the questionnaire will be carried out using the SPSS. After the data is collected and tested for reliability and validity, the TRI calculation is carried out based on the values of the four main dimensions derived from the questionnaire.

In this study, each of the four dimensions of TRI will have three statements that will be asked of respondents, so that in total, there will be 12 statements that will be given to respondents related to the readiness to adopt digital technology based on TRI. There are several equations used in the TRI calculation process, which can be seen in Equation 1 to Equation 4 [22], [23].

$$Statement\ Weight = \frac{25\%}{\sum Variable\ Score} \quad (1)$$

$$Statement\ Score = \frac{(number\ of\ answer * score) * statement\ weight}{number\ of\ respondents} \quad (2)$$

$$Dimension\ Score = \sum Statement\ Score \quad (3)$$

$$TRI\ Total = \sum Dimension\ Score \quad (4)$$

Statement Weight is the weight of each statement in a variable, calculated by dividing 25% by the total score of the variable. Statement Score is the score of each statement obtained from the multiplication of the number of answers, and the score is multiplied by the weight of the statement and then divided by the number of respondents. Dimension Score is the accumulation of all Statement Scores in a particular dimension. Finally, TRI Total is the total of all Dimension Scores.

The next stage is Segmentation Analysis with AHC. Segmentation is carried out using the AHC method. This stage includes determining the optimal number of clusters using the dendrogram method, using the linkage method to combine clusters based on the level of similarity, and interpreting clustering results to identify the characteristics of each MSME group based on the TRI score. The last stage is to carry out the Interpretation and Discussion of Results. After segmentation is complete, the clustering results are analyzed to understand the pattern of MSME technology readiness in border areas.

III. RESULT

The data collection for the TRI questionnaire in this study involved MSMEs from the border areas of Indonesia and Malaysia, specifically the Nunukan and Sebatik regions. The respondent selection technique used a purposive sampling approach, where the respondents were participants in a digital technology adoption training program. Respondents completed a total of 47 questionnaires. With respondents' characteristics being quite homogeneous in the context of this study, it is expected that this research can provide representative results. Each respondent in this study will answer 12 statements related to TRI, representing each dimension of TRI by three variables.

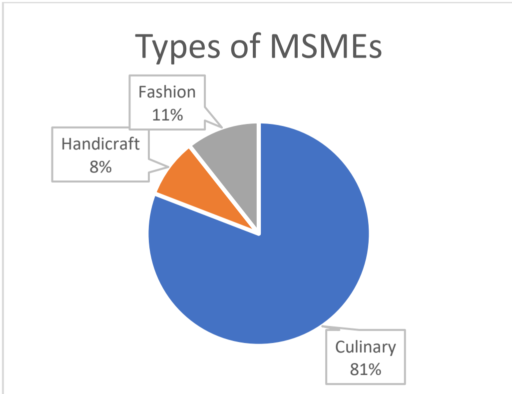

Figure 2. Types of MSMEs

Figure 2 shows the statistics on the types of MSMEs that were respondents in this study. Most respondents run businesses in the culinary field, many of them utilizing seaweed as one of the main ingredients, which has become a distinctive feature of MSMEs in these border regions.

After the data was collected, the respondents' answers were converted or weighted using a Likert scale of 1-5. Next, testing processes, including validity and reliability tests, were conducted. In this study, these testing processes were carried out using SPSS software. The results of the reliability test in this study can be seen in Figure 3.

Reliability Statistics

Cronbach's Alpha	N of Items
,917	12

Figure 3. Reliability Testing

Figure 3 shows that the reliability test result of 0.917 indicates that the measurement tool used has a very high level of consistency, with values above 0.9 indicating excellent reliability. In general, the reliability value is measured using Cronbach's Alpha coefficient, which ranges from 0 to 1. The higher the value, the better the consistency.

In addition to conducting the reliability test, a validity test was also performed. The results of the validity test can be seen in Table I. In Table I, if the calculated r > table r (two-tailed test

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with a significance level of 0.05), then the instrument or the items of the questions are significantly correlated with the total score and are declared valid.

TABLE I. VALIDITY TESTING

Indicator	R Calculated	Result
OP1	0,616	Valid
OP2	0,571	Valid
OP3	0,690	Valid
INNO1	0,638	Valid
INNO2	0,660	Valid
INNO3	0,661	Valid
DIS1	0,656	Valid
DIS2	0,805	Valid
DIS3	0,842	Valid
INS1	0,828	Valid
INS2	0,847	Valid
INS3	0,875	Valid

Based on Table I of the validity test results, all indicators from all dimensions of TRI have a calculated r value more significant than the table r value (0.2876), meaning that all the questionnaire indicators are valid.

In this study, the TRI process for adopting digital technology for MSMEs in border areas will be carried out per dimension, starting from Optimism to Insecurity. Furthermore, the value of each dimension will be calculated to obtain the overall TRI value. After all TRI dimensions have been measured, the results for each TRI dimension in this study can be seen in Figure 3.

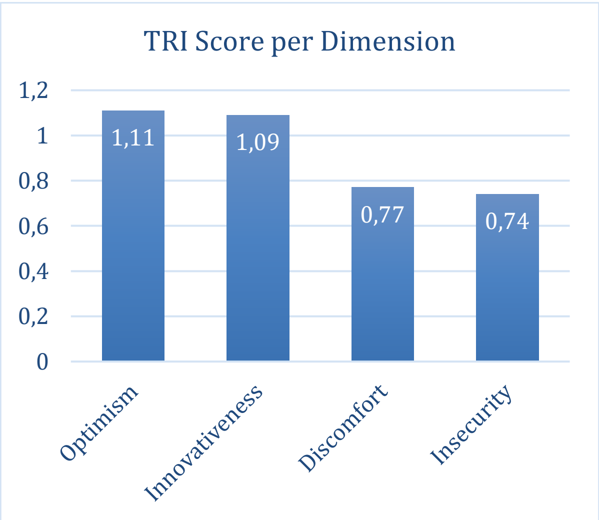

Figure 4. TRI Score per Dimension

From the TRI value calculations per variable, as shown in Figure 4, it can be concluded that the Optimism dimension (1.11) has the highest value, indicating that MSMEs in border regions have a reasonably positive outlook on technology. The Innovativeness dimension (1.09) is almost equal to Optimism, meaning that MSMEs are quite open to experimenting with new technology. The main obstacles are found in Discomfort (0.77) and Insecurity (0.74), which are lower than Optimism and Innovativeness, indicating that there are still concerns and Discomfort in using digital technology.

The final step in the TRI measurement process is summing all the TRI dimension values according to Equation 4, resulting in the following:

$$TRI\ Total = 1{,}11 + 1{,}09 + 0{,}77 + 0{,}74 = \mathbf{3{,}72}$$

A TRI score of 3.72 indicates that MSMEs in border regions have a high level of digital readiness (High TRI) overall. They demonstrate good digital preparedness, a positive attitude toward technology, and openness to innovation. However, challenges remain regarding comfort in using technology and trust in its security.

In this study, the clustering process was conducted using the AHC technique, applying Ward's Method and Squared Euclidean Distance as the distance metric. The clustering was based on the four dimensions of the Technology Readiness Index (TRI). This method was selected due to its effectiveness in minimizing within-cluster variance, leading to more optimal and homogeneous groupings.

Based on the initial analysis of the dendrogram and agglomeration schedule (figure 4), two clusters are the most suitable number for this MSME dataset. To ensure a more structured clustering result, a re-clustering process was performed using the single solution approach, maintaining the number of clusters at two, as determined from the initial analysis. The results of this process reflect the existence of two main groups in MSMEs' adoption of digital technology based on the four TRI dimensions.

The dendrogram visualization is shown in Figure 4. The dendrogram illustrates that the data has been divided into two main clusters with distinct differences. The generated dendrogram demonstrates the hierarchical structure of the clustering process, where objects with high similarity are grouped first before eventually forming the two main clusters. Based on the dendrogram, the separation of the two clusters was determined at the stage where a significant change in linkage distance was observed. This confirms that MSMEs within each cluster have similar digital readiness characteristics, while the differences between clusters primarily reflect variations in technology adoption based on the four TRI dimensions.

Cluster membership based on the Hierarchical Clustering process can be seen in Figure 5. This figure presents the number of MSMEs grouped into Cluster 1 and Cluster 2 based on the clustering results. This cluster reflects the digital readiness patterns of MSMEs, where each cluster exhibits distinct characteristics across the four dimensions of the TRI.

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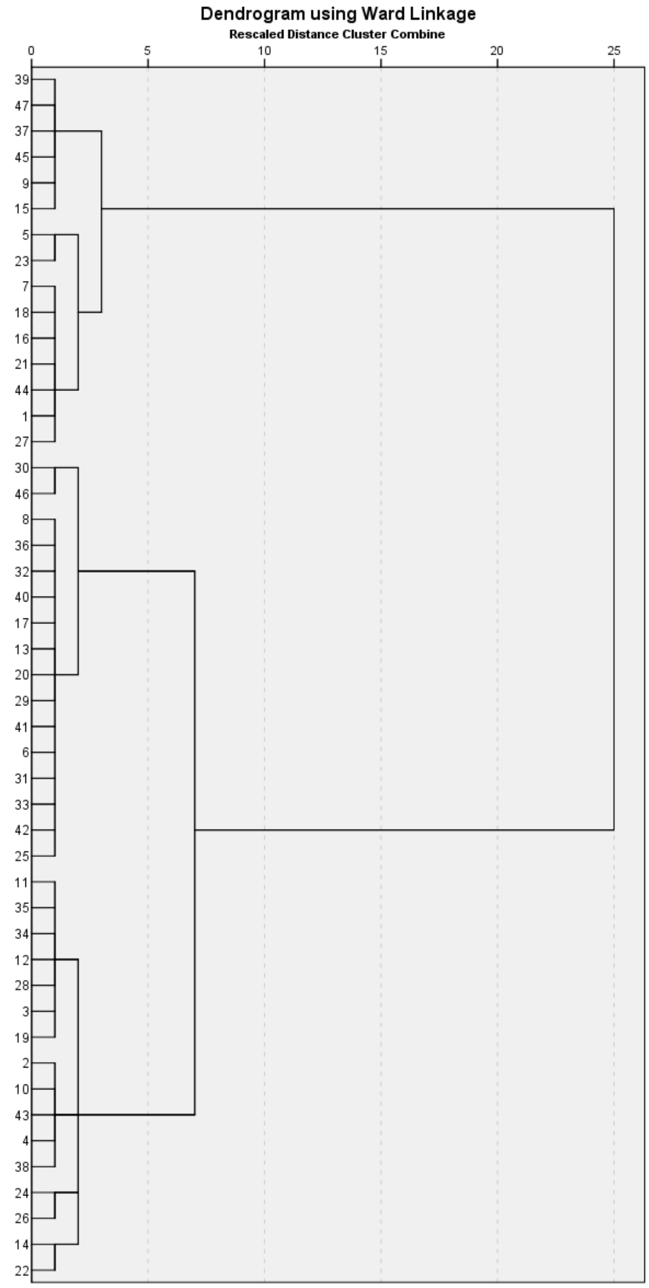

Figure 5. Cluster Membership

Based on the clustering results, two main clusters were identified, as shown in Figure 5. Cluster 1 consists of 15 MSMEs, while Cluster 2 includes 32 MSMEs. Cluster 1 represents MSMEs with a higher level of digital technology adoption readiness. Businesses in this cluster exhibit greater optimism and innovativeness, as indicated by higher average scores in the Optimism and Innovativeness dimensions. These MSMEs are more progressive and adaptive to technology, making them better prepared to implement digital solutions in their operations.

On the other hand, Cluster 2 comprises MSMEs with a lower level of technology adoption readiness compared to Cluster 1. These businesses may face more psychological and technical challenges in adopting digital technology. These findings are a foundation for designing strategies to enhance digital readiness among MSMEs, particularly for those struggling with technological adoption barriers.

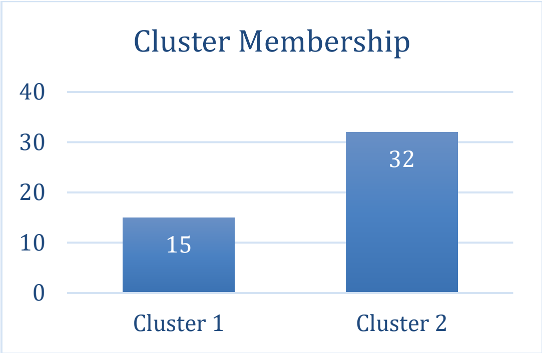

Figure 6. Cluster Membership

Based on the analysis of cluster characteristics, Cluster 1 tends to have a higher level of Optimism and Innovativeness, along with a lower level of Discomfort and Insecurity, categorizing them as MSMEs with high digital readiness. MSMEs in this cluster exhibit a proactive attitude toward adopting new technologies, are more innovative, and strongly believe in the benefits of digital technology. Conversely, Cluster 2 represents MSMEs with lower digital readiness than Cluster 1, which may face more significant psychological or technical barriers in adopting digital technology. MSMEs in this cluster may struggle to comprehend technology or encounter resource constraints when adopting digital solutions.

These findings highlight the existence of a digital readiness gap among MSMEs. Only a small portion (Cluster 1) is fully prepared, while most (Cluster 2) still face significant adoption challenges. Therefore, an appropriate strategy is required to enhance the digital readiness of MSMEs in Cluster 2, such as through technology training, digital business mentoring, or policy support to facilitate broader technology adoption.

From a research contribution perspective, this study successfully achieves its primary objective to identify MSME digital readiness segmentation using a TRI-based hierarchical clustering approach. Unlike previous studies that assess MSME digital readiness at an aggregate level, this research reveals the presence of clusters with distinct characteristics, demonstrating that digitalization strategies should not be applied uniformly but tailored to each MSME cluster's specific characteristics.

IV. CONCLUSION

The results of this study confirm that what was expected in the Introduction has been successfully addressed through the Results and Analysis section. Using AHC with Ward's Method and Squared Euclidean Distance, the clustering process has effectively grouped MSMEs into two main clusters based on their readiness to adopt digital technology. This segmentation validates the initial assumption that there is a digital readiness gap among MSMEs, where Cluster 1 consists of digitally ready MSMEs. In contrast, Cluster 2 includes MSMEs, which are still

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facing challenges in adopting technology. Furthermore, the findings of this study contribute to the state of the art in technology adoption research by demonstrating a systematic approach to MSME segmentation based on the dimensions of the TRI. In this study, the TRI score of 3.72 is categorized as High TRI, reflecting a higher level of technology readiness. This study is particularly relevant for MSMEs in border areas, where digital transformation is crucial in enhancing competitiveness and economic integration. The segmentation results provide valuable insights for policymakers and stakeholders to design targeted interventions that support technology adoption among MSMEs in border areas. For future research, these findings open up opportunities for further development, particularly in refining the clustering model by incorporating additional socio-economic and geographical factors that influence digital technology adoption, especially in border regions.

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