



Modeling E-Payment Adoption and its Impact on MSME Financial Inclusion in North Kolaka

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ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) play a crucial role in Indonesia's economic development; however, the adoption of e-payment systems in North Kolaka Regency remains relatively low. This study aims to model and analyze the adoption dynamics of e-payment among MSMEs using an SEIR (Susceptible-Exposed-Infected-Recovered) framework. Based on survey data from 485 MSMEs, simulations were conducted using Python to determine the spread and sustainability of adoption behavior. The results reveal that a majority of MSMEs are still unfamiliar with e-payment systems, while the proportion of active users remains limited. The numerical simulation yields a basic reproduction number of $R_0 = 0.4939$, indicating that e-payment adoption has not yet reached a sustainable level. To enhance the growth of e-payment usage and strengthen financial inclusion, policy strategies should focus on improving digital financial literacy, providing continuous incentives, and integrating MSMEs into broader go-digital programs.

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1. INTRODUCTION

Micro, Small, and Medium Enterprises (MSMEs) contribute significantly to Indonesia's economy by creating jobs and increasing gross domestic product [1], [2]. However, limited access to formal financial services continues to hinder their growth and competitiveness [3], [4], emphasizing the urgency of advancing financial inclusion. The rapid development of financial technology, particularly electronic payment systems (e-payments), offers promising opportunities to accelerate inclusion by enabling faster, more efficient, and secure financial transactions [5], [6]. Despite these opportunities, the adoption rate of e-payments among MSMEs remains low. In Indonesia, only around 35% of MSMEs have adopted digital payment systems, reflecting persistent challenges such as limited

financial literacy [7], [8], low technological trust, inadequate digital infrastructure, and perceived adoption costs [9], [10]. These barriers highlight the need for a comprehensive strategy to optimize e-payments as a key instrument for strengthening financial inclusion [11], [12], [13].

At the national level, e-payments have been recognized as a catalyst for inclusive finance, yet research employing mathematical modelling to analyze adoption dynamics remains limited [14]. Such approaches are essential for identifying key determinants of adoption and quantitatively simulating the potential impacts of different policy strategies [15], [16], [17]. This gap is significant, not only in the Indonesian context but also in enriching global understanding of how MSMEs can leverage financial technology to expand inclusive financial access [18], [19].

In North Kolaka Regency, where more than 480 MSMEs operate, digital literacy gaps, weak infrastructure, and resistance to technological change continue to restrict e-payment penetration [20], [21]. Limited digital infrastructure, low financial literacy, and resistance to technological change remain major barriers. Moreover, specific empirical data on e-payment adoption among MSMEs in this region remain scarce [22], [23]. A study in Kolaka Regency indicated that knowledge and ease of use influence the younger generation's interest in technology-based financial transactions. However, studies specifically examining the impact of e-payments on MSME financial inclusion in North Kolaka remain rare.

Therefore, this research aims to (1) develop a survey-based SEIR model to describe the dynamics of e-payment adoption, (2) analyze the internal and external factors influencing adoption, and (3) recommend effective policy strategies to enhance e-payment-based financial inclusion among MSMEs in North Kolaka, thereby contributing to broader national and global financial inclusion efforts [24], [25], [26], [27].

2. RESEARCH METHOD

This study employs a quantitative approach by developing an SEIR model to analyze e-payment adoption patterns among MSMEs in North Kolaka Regency. Primary data were obtained from a survey of 485 MSMEs using purposive sampling, which targeted businesses with the potential to adopt digital financial services. While this technique is effective for reaching specific groups, it carries the risk of bias if MSMEs with low digital literacy or those that have never used e-payments are underrepresented. The research instruments consisted of questionnaires and interviews, both of which relied on self-reported data. Such dependence may introduce bias, as respondents might exaggerate positive behaviours or underreport challenges related to the adoption of financial technology. The SEIR model was adapted to the context of e-payment adoption by dividing the MSME population into four compartments: Susceptible (MSMEs unfamiliar with e-payment), Exposed (MSMEs familiar with but not yet using e-payment), Infected (MSMEs starting to use e-payment), and Recovered (MSMEs no longer actively using e-payment). Parameter estimation was based on survey data and secondary sources, while model analysis was conducted using Python for data processing and Maple for mathematical modelling and simulation.

This study did not include a control or comparison group with MSMEs from other regions or sectors. As a result, attributing changes solely to e-payment adoption may overlook the influence of external factors. Moreover, the SEIR model remains experimental, relying on simplifying assumptions and parameters that are sensitive to variation, which must be considered when interpreting the results. To strengthen validity and generalizability, future research should incorporate triangulation methods—such as alternative models, cross-regional comparisons, or qualitative approaches to provide a more comprehensive understanding of the factors influencing e-payment adoption among MSMEs.

3. RESULT AND ANALYSIS

This research developed an SEIR (Susceptible–Exposed–Infected–Recovered) model to map the adoption dynamics of e-payment among MSMEs. The use of the SEIR framework, which originates from epidemiological modeling, is justified by its ability to represent the diffusion of innovation and behavioral contagion processes in socio-economic systems, as demonstrated in previous studies on technology and information diffusion [14], [15]. In this context, MSMEs in the infected class that have started using e-payment as a transaction method can influence other enterprises through information sharing or social interactions, while those in the recovered class represent active and loyal users who consistently use e-payment in business operations.

The model divides MSMEs into four compartments: susceptible (S), MSMEs that are unaware of e-payment; exposed (E), MSMEs that are aware but have not yet adopted; infected (I), MSMEs that have started using e-payment; and recovered (R), MSMEs that actively and consistently use it. The flow diagram and variables are presented in Figure 1 and Table 1, respectively.

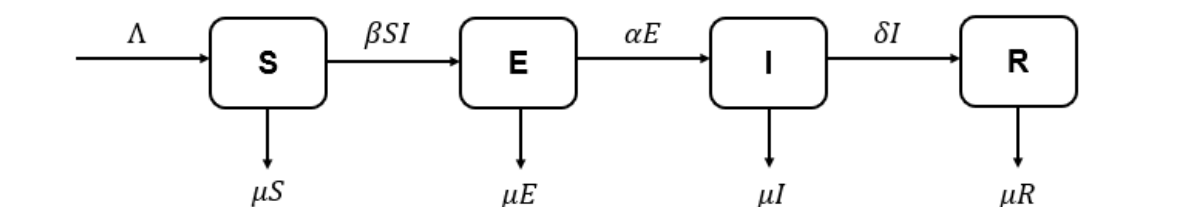


Figure 1. Compartment Diagram of E-payment Usage

The explanation of Figure 1 can be seen on Table 1.

Table 1. Description of Variables and Parameters

Variables and Parameters	Description	Unit
N	Number of MSMEs in North Kolaka	unit
S	Number of MSMEs that has not yet known about e-payment	unit
E	Number of MSMEs that has known but not used e-payment	unit
I	Number of MSMEs that has started using e-payment	unit
R	Number of MSMEs that actively uses e-payment	unit
Λ	Rate of newly established MSMEs, and MSMEs that has not yet known about e-payment	unit/month
β	Rate of MSMEs exposed to e-payment	1/month
α	Rate of MSMEs that has been familiar with e-payment then trying it	1/month
δ	Rate of MSMEs actively using e-payment as a transaction method	1/month
μ	Rate of MSMEs closing down or no longer active in digitalized system	1/month

From Figure 1, we obtained the following system of differential equations (1)-(4):

$$\frac{ds}{dt} = \Lambda - \beta si - \mu s, \quad (1)$$

$$\frac{de}{dt} = \beta si - \alpha e - \mu e, \quad (2)$$

$$\frac{di}{dt} = \alpha e - \delta i - \mu i, \quad (3)$$

$$\frac{dr}{dt} = \delta i - \mu r. \quad (4)$$

Data processing followed a sequential structure: survey data $\rightarrow$ parameter estimation $\rightarrow$ model simulation and validation. Parameters such as adoption rate (α), exposure rate (β), and retention rate (δ) were estimated from survey results and secondary data. Model validation was conducted through sensitivity analysis and statistical comparison between observed and simulated data using R^2 and mean absolute percentage error (MAPE) to ensure the model's realism and reliability. The purposive sampling method used in data collection may introduce selection bias; however, this was mitigated through respondent diversification across business sectors and scales.

3.1 SEIR Model Equilibrium Point

The points s, e, i, r are the equilibria of the system (1) - (4) if they satisfy the conditions $\frac{ds}{dt} = 0, \frac{de}{dt} = 0, \frac{di}{dt} = 0, \frac{dr}{dt} = 0$. Within the system, there exists two equilibria, i.e. the free e-payment equilibrium and the e-payment equilibrium. Therefore, the following equations are obtained (5)-(8):

$$\Lambda - \beta si - \mu s = 0, \quad (5)$$

$$\beta si - \alpha e - \mu e = 0, \quad (6)$$

$$\alpha e - \delta i - \mu i = 0, \quad (7)$$

$$\delta i - \mu r = 0. \quad (8)$$

Free e-payment equilibrium

From equations (5) - (8), free e-payment equilibrium and e-payment equilibrium. The free e-payment equilibrium solution is marked with $E = I = 0$, which means there are no MSMEs that has known and used e-payment. If assumed that $E = I = 0$ and it is substituted to equations (5), it is obtained that (9):

$$\Lambda - \beta si - \mu s = 0,$$

$$\Lambda - (\beta i + \mu)s = 0,$$

$$(\beta i + \mu)s = \Lambda, \quad (9)$$

$$s = \frac{\Lambda}{\beta i + \mu}$$

Since the parameter β is the exposed input parameter, and $i = 0$, therefore it must be that $\beta = 0$, thus it is obtained that $s = \frac{\Lambda}{\mu}$. Therefore, the free e-payment equilibrium is $E_0 = (s, e, i, r) = (\frac{\Lambda}{\mu}, 0, 0, 0)$.

E-payment Endemic Equilibrium

Next, the e-payment endemic equilibrium which marked with $s^* \neq 0, e^* \neq 0, i^* \neq 0, r^* \neq 0$, which shows MSMEs implemented e-payment, was determined. Based on the equation (5) - (8), then the e-payment endemic equilibrium point is obtained as $E^* = (s^*, e^*, i^*, r^*) = (\frac{\Lambda}{\beta i^* + \mu}, \frac{\beta s^* i^*}{\alpha + \mu}, \frac{\alpha e^*}{\delta + \mu}, \frac{\mu}{\delta i^*})$.

3.2 Basic Reproduction Equilibrium

The calculation of basic reproduction number R_0 was done using the next generation matrix. Constructing the next generation matrix involved the addition of MSMEs that are familiar with e-payment. In this method, MSMEs that has known about e-payment and started using e-payment, which was given on equation (2) and (3), are shown as follows:

$$\frac{de}{dt} = \beta si - \alpha e - \mu e,$$

$$\frac{di}{dt} = \alpha e - \delta i - \mu i.$$

The next generation matrix is given by $K = FV^{-1}$, where the matrix F describes new MSMEs, and V^{-1} describes the transition of e-payment exposure. MSMEs that have been familiar with and used e-payment are E and I . Jacobian matrices on the free e-payment equilibrium F and V were obtained by taking partial derivatives on E and I as follows (15):

$$F = \frac{\partial F_1 E_0}{\partial (e, i)} = \begin{bmatrix} \frac{\partial F_1}{\partial e} & \frac{\partial F_1}{\partial i} \\ \frac{\partial F_2}{\partial e} & \frac{\partial F_2}{\partial i} \end{bmatrix} = \begin{bmatrix} 0 & \beta s \\ 0 & 0 \end{bmatrix}, \quad (10)$$

$$V = \frac{\partial V_1 E_0}{\partial (e, i)} = \begin{bmatrix} \frac{\partial V_1}{\partial e} & \frac{\partial V_1}{\partial i} \\ \frac{\partial V_2}{\partial e} & \frac{\partial V_2}{\partial i} \end{bmatrix} = \begin{bmatrix} \alpha + \mu & 0 \\ -\alpha & \delta + \mu \end{bmatrix}. \quad (11)$$

Next, looking for the invers of V , it is obtained that:

$$(V)^{-1} = \begin{bmatrix} \frac{1}{\alpha + \mu} & 0 \\ \frac{\alpha}{(\alpha + \mu)(\delta + \mu)} & \frac{1}{\delta + \mu} \end{bmatrix}. \quad (12)$$

Then, K is the next generation matrix, where $F \times V^{-1}$ is obtained as:

$$K = \begin{bmatrix} \frac{\beta \Lambda \alpha}{\mu(\alpha + \mu)(\delta + \mu)} & \frac{\beta \Lambda}{\mu(\delta + \mu)} \\ 0 & 0 \end{bmatrix}. \quad (13)$$

Next, the characteristic equation of K is obtained as follows:

$$\det(\lambda I - K) = 0,$$

$$K = \begin{bmatrix} \lambda - \frac{\beta \Lambda \alpha}{\mu(\alpha + \mu)(\delta + \mu)} & \frac{\beta \Lambda}{\mu(\delta + \mu)} \\ 0 & \lambda \end{bmatrix} \text{ or } \left(\lambda - \frac{\beta \Lambda \alpha}{\mu(\alpha + \mu)(\delta + \mu)} \right) \lambda = 0. \quad (14)$$

Since $R_0 = \rho(FV^{-1})$ is the spectral radius or the dominant eigenvalue of K , thus it is obtained that the basic reproduction number is

$$R_0 = \frac{\beta \Lambda \alpha}{\mu(\alpha + \mu)(\delta + \mu)}. \quad (15)$$

Next, the stability of the free e-payment equilibrium and the endemic e-payment equilibrium is analyzed.

3.3 Model Stability Analysis

Using linearization on the model (1) - (4), Jacobian matrix is obtained as follows (16)

$$= \begin{bmatrix} -\beta i - \mu & 0 & -\beta s & 0 \\ \beta i & -\alpha - \mu & \beta s & 0 \\ 0 & \alpha & -\delta - \mu & 0 \\ 0 & 0 & \delta & -\mu \end{bmatrix} \quad (16)$$

Next, the stability of the free e-payment equilibrium (E_0) and the e-payment equilibrium (E_1) is analysed.

Stability analysis of free e-payment equilibrium

By evaluating the Jacobian matrix (16) around E_0 , it is obtained that (17):

$$JE_0 = \begin{bmatrix} -\mu & 0 & -\beta s & 0 \\ 0 & -\alpha - \mu & \beta s & 0 \\ 0 & \alpha & -\delta - \mu & 0 \\ 0 & 0 & \delta & -\mu \end{bmatrix}$$

To determine the stability of E_0 , the eigenvalues of the matrix JE_0 was determined by using $\det(JE_0 - \lambda I) = 0$, where λ is the eigenvalue and I is the identity matrix. Thus, we obtain that $\det(JE_0 - \lambda I) = 0$ as

$$\det \left(\begin{bmatrix} \lambda + \mu & 0 & \beta s & 0 \\ 0 & \lambda + (\alpha + \mu) & -\beta s & 0 \\ 0 & -\alpha & \lambda + (\delta + \mu) & 0 \\ 0 & 0 & -\delta & \lambda + \mu \end{bmatrix} \right) = 0,$$

with

$$\begin{aligned} x &= \alpha + \mu, \\ y &= \delta + \mu. \end{aligned}$$

Therefore, from cofactor expansion, it is obtained that

$$\lambda + \mu \left(\begin{bmatrix} \lambda + x & -\beta s & 0 \\ -\alpha & \lambda + y & 0 \\ 0 & -\delta & \lambda + \mu \end{bmatrix} \right) = 0,$$

$$\Leftrightarrow (\lambda + \mu)((\lambda + x) + (\lambda + y) + (\lambda + \mu) - (\lambda + \mu)(-\alpha)(-\beta s)) = 0,$$

$$\Leftrightarrow (\lambda + \mu)(\lambda + \mu)((\lambda + x) + (\lambda + y) - (-\alpha)(-\beta s)) = 0,$$

$$\Leftrightarrow (\lambda + \mu)(\lambda + \mu)(\lambda^2 + (x + y)\lambda + xy - \alpha\beta s) = 0,$$

$$\Leftrightarrow (\lambda + \mu)(\lambda + \mu)(\lambda^2 + a\lambda + b) = 0,$$

with

$$\begin{aligned} a &= x + y, \\ b &= xy - \alpha\beta s. \end{aligned}$$

From equation (16), it is obtained that

$$\lambda = -\mu \text{ and } \lambda^2 + a\lambda + b = 0 \quad (17)$$

To determine the eigenvalues from equation (17), Routh-Hurwitz criterion is used. According to Routh-Hurwitz criterion, the roots of the characteristic equation of equation (17) are real and negative if the following conditions are satisfied:

$$\begin{aligned} H_1 &= |a| > 0, \\ H_2 &= \begin{vmatrix} a & 0 \\ 1 & b \end{vmatrix} > 0. \end{aligned}$$

The following is the explanation.

$$H_1 = |a| = a = x + y = (\alpha + \mu) + (\delta + \mu) > 0,$$

$$H_2 = \begin{vmatrix} a & 0 \\ 1 & b \end{vmatrix} = ab,$$

thus

$$\begin{aligned} ab &= (x + y)(xy - \alpha\beta s) \\ &= ((\alpha + \mu) + (\delta + \mu))((\alpha + \mu)(\delta + \mu) - \alpha\beta s) \\ &= (\alpha + \beta + 2\mu)((\alpha + \mu)(\delta + \mu) - \alpha\beta s). \end{aligned}$$

It is known that

$$R_0 = \frac{\beta\Lambda\alpha}{\mu(\alpha+\mu)(\delta+\mu)} \Leftrightarrow \alpha\beta s = (\alpha + \mu)(\delta + \mu)R_0,$$

thus, it is obtained that

$$\begin{aligned} ab &= (\alpha + \beta + 2\mu)((\alpha + \mu)(\delta + \mu) - (\alpha + \mu)(\delta + \mu)R_0) \\ &= (\alpha + \beta + 2\mu)((\alpha + \mu)(\delta + \mu)(1 - R_0)), \end{aligned}$$

or in other words, if $R_0 < 1$, then $H_2 > 0$.

According to Hurwitz criterion, the roots of the equation are real and negative, with $H_1, H_2 > 0$, thus the equilibrium E_0 is stable. With the stability theory, when $R_0 < 1$, then the free e-payment equilibrium is locally asymptotically stable. It also implies that vice versa, if $R_0 > 1$, then the free e-payment equilibrium is unstable.

Stability analysis of the endemic e-payment equilibrium

By evaluating the Jacobian matrix (16) around E_1 , it is obtained that (18):

$$JE_1 = \begin{bmatrix} -\beta i^* - \mu & 0 & -\beta s^* & 0 \\ \beta i^* & -\alpha - \mu & \beta s^* & 0 \\ 0 & \alpha & -\delta - \mu & 0 \\ 0 & 0 & \delta & -\mu \end{bmatrix}$$

To determine the stability of the e-payment equilibrium, first the characteristic equation of the matrix JE_1 , i.e.

$$\det(JE_1 - \lambda I) = 0, \text{ or } \lambda^4 + a\lambda^3 + b\lambda^2 + c\lambda + d \quad (18)$$

were

$$\begin{aligned} a &= \beta i^* + \alpha + \delta + 4\mu, \\ b &= \alpha\beta i^* - \alpha\beta s^* - \beta\delta i^* + 3\beta i^*\mu + \alpha\delta + 3\alpha\mu + 3\delta\mu + 6\mu^2, \\ c &= \alpha\beta\delta i^* + 2\alpha\beta i^*\mu - 2\alpha\beta\mu s^* + 2\alpha\delta i^*\mu + 3\beta i^*\mu^2 + 2\alpha\delta\mu + 3\alpha\mu^2 + 4\mu^3 + 3\delta\mu^2, \\ d &= \alpha\beta\delta\mu i^* + \alpha\beta\mu^2 i^* - \alpha\beta\mu^2 s^* + \beta\delta\mu^2 i^* + \beta\mu^3 i^* + \alpha\delta\mu^2 + \alpha\mu^3 + \delta\mu^3 + \mu^4. \end{aligned}$$

According to Routh-Hurwitz criterion, the roots of the characteristic equation are real and negative if they satisfy the following requirements:

$$H_1 = a > 0, \text{ or}$$

$$H_2 = \begin{vmatrix} a & 1 \\ c & b \end{vmatrix} > 0, \text{ or } ab - c > 0, \text{ and satisfies } a, b > 0,$$

$$H_3 = \begin{vmatrix} a & c & 0 \\ 1 & b & d \\ 0 & a & c \end{vmatrix} > 0, \text{ or } abc > c^2 + a^2d, \text{ and satisfies } a, b, c > 0,$$

$$H_4 = \begin{vmatrix} a & c & 0 & 0 \\ 1 & b & d & 0 \\ 0 & a & c & 0 \\ 0 & 1 & b & d \end{vmatrix} > 0, \text{ or } abcd > a^2d^2 + c^2d, \text{ and satisfies } a, b, c, d > 0.$$

If the requirements are satisfied, the real part of the roots of equation (15) is negative. According to the Routh-Hurwitz criterion, this indicates that the e-payment equilibrium is locally asymptotically stable. In practical terms, if key parameters—such as the adoption rate and digital literacy—are improved to meet these conditions, the adoption of e-payments can achieve long-term stability.

3.4 Parameter Sensitivity Analysis of R_0

Sensitivity analysis was done to show the effects of the parameters in the basic reproduction number on the model (1) - (4). The parameters can increase or decrease the basic reproduction number (R_0). If the parameter

values experienced increase or decrease, and vice versa, it means that there is a connection among each other, as shown in Table 2.

Definition 1 Normalization index is obtained by normalization of R_0 which were differentiated on the parameter p , is defined as follows:

$$C_p^{R_0} = \frac{\partial R_0}{\partial p} \times \frac{p}{R_0}. \quad (19)$$

Table 2. Test result of R_0 on the parameter

Parameter	Sensitivity Analysis Result	Sensitivity Index
$C_{\Lambda}^{R_0}$	1	+
$C_{\mu}^{R_0}$	$\left(-\frac{\beta\Lambda\alpha}{\mu^2(\alpha+\mu)(\delta+\mu)} - \frac{\beta\Lambda\alpha}{\mu(\alpha+\mu)^2(\delta+\mu)} - \frac{\beta\Lambda\alpha}{\mu(\alpha+\mu)(\delta+\mu)^2} \right) \mu^2(\alpha+\mu)(\delta+\mu)$	−
$C_{\beta}^{R_0}$	$\frac{\beta\Lambda\alpha}{1}$	+
$C_{\alpha}^{R_0}$	$\left(\frac{\beta\Lambda}{\mu(\alpha+\mu)(\delta+\mu)} - \frac{\beta\Lambda\alpha}{\mu(\alpha+\mu)^2(\delta+\mu)} \right) \mu(\alpha+\mu)(\delta+\mu)$	+
$C_{\delta}^{R_0}$	$\frac{\beta\Lambda}{\delta}$ $-\frac{\delta}{\delta+\mu}$	−

3.5 Numerical Simulation

The initial data used are 485 MSMEs which were categorized into four compartments and could be seen in Table 3. Parameter values could also be seen in Table 3.

Table 3. Variable and Parameter Values

Variable	Value	Parameter	Value
S	334	Λ	0.68
E	11	β	0.88
I	140	α	0.87
R	0	δ	0.57
-	-	δ	0.68

If the values are substituted into system (15), the result is $R_0 = 0.4939 < 1$. This indicates that the number of MSMEs using e-payments as a transaction method remains very limited. In practical terms, each MSME that adopts e-payments is, on average, able to influence less than one additional MSME to adopt, meaning that adoption is not yet self-sustaining. This highlights the need for external support—such as literacy programs, incentives, and infrastructure improvements—to accelerate adoption and strengthen financial inclusion. This showed that active users would keep declining into the E_0 point if there were no efforts to increase the use of e-payment among MSMEs. The simulation result can be seen in Figure 2.

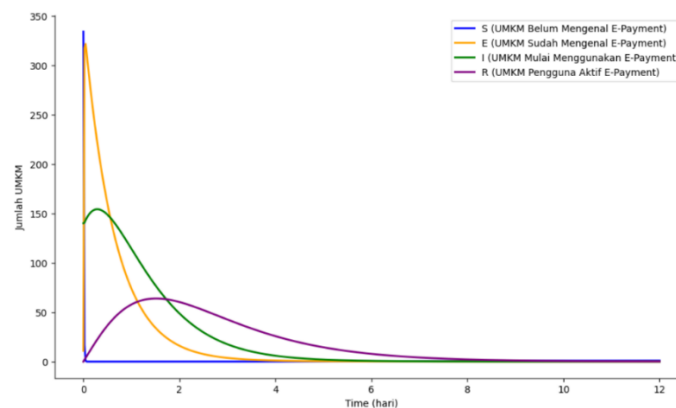


Figure 2. SEIR Model Simulation

Figure 2 illustrates the dynamics of e-payment adoption among MSMEs in North Kolaka through four SEIR compartments. At the beginning of the simulation, most MSMEs were in compartment S (unfamiliar with e-

payments), totaling 334 units. This number decreased significantly as they shifted to compartment E (familiar but not yet using), which initially contained only 11 MSMEs, then increased due to the transfer from S before declining as some began to adopt e-payments. Compartment I (MSMEs that started using e-payments) began with 140 units, rose briefly, and then declined until stabilizing on the 8th day. Meanwhile, compartment R (active e-payment users) started at a very low level, increased to 60 within the first two days, and then declined before stabilizing on the 10th day. This pattern illustrates a rapid transition from unfamiliarity to initial trial; however, retention as active users remain low, which limits the overall contribution of e-payments to financial inclusion in North Kolaka. The simulation results confirm that the high number of MSMEs that stop or remain inactive in using e-payments is a major barrier to their contribution to financial inclusion in North Kolaka. In other words, while initial adoption is evident, continued usage remains weak. This challenge is strongly influenced by local socioeconomic factors—such as limited digital infrastructure, cultural preferences for cash-based transactions, and low levels of financial literacy—that reduce the willingness and ability of MSMEs to consistently use e-payments. Addressing these local barriers is therefore crucial to ensuring that e-payments can make a meaningful impact on financial inclusion in the region. These findings highlight the urgency of strategies aimed at strengthening user retention rather than merely introducing e-payments. The recommended strategies include:

- Reducing the rate of inactive MSMEs (μ) through technical assistance, sustainable incentives, improvements in digital infrastructure, and programs that promote continued use
- Encouraging MSMEs already familiar with e-payments to become regular users through practical training, literacy campaigns, and loyalty programs; and
- Expanding the user base through regional go-digital programs.

Overall, this study demonstrates that enhancing digital literacy, improving infrastructure, providing sustainable incentives, and implementing go-digital programs are key strategies for expanding e-payment adoption. However, it is important to note that these findings are based on a simplified SEIR model, which does not fully capture real-world complexities such as governmental policies, socioeconomic disparities, or local businesses' resistance to change. These factors may significantly influence the effectiveness of the recommended strategies and should be carefully considered in future research and policy implementation. The implementation of appropriate policies will not only increase financial inclusion among MSMEs in North Kolaka but also contribute to a more inclusive digital economic transformation in Indonesia. Furthermore, future studies could benefit from applying alternative methods or making comparisons with other regions or countries facing similar challenges, to strengthen the generalizability and practical relevance of these findings.

4. CONCLUSION

This study demonstrates that although e-payment adoption among MSMEs in North Kolaka has begun, the number of active users remains relatively low, thereby limiting its overall impact on financial inclusion. The SEIR model identifies the high proportion of inactive MSMEs as a major constraint, emphasizing the importance of implementing strategies such as enhancing digital and financial literacy, providing sustainable adoption incentives, introducing loyalty programs, and expanding participation through regional go-digital initiatives. These interventions are expected to strengthen MSMEs' long-term resilience and foster inclusive digital economic growth.

Nevertheless, the results should be interpreted with caution, given the simplifying assumptions and parameter sensitivity inherent in the SEIR framework. The model's findings, while informative, may not be fully generalizable to different regional or economic contexts. Therefore, future research should incorporate alternative modeling approaches, qualitative insights, and cross-regional comparative analyses to deepen understanding of e-payment adoption dynamics and provide a more robust foundation for evidence-based policy recommendations for MSMEs.

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