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Digital Signature Trends and Forecast (2021 – 2022) for Indonesian Government Affairs

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ABSTRACT

This study examines digital signature transaction trends in Indonesian government affairs from 2021 to 2022, focusing on forecasting future patterns to support infrastructure planning. The research was motivated by the Indonesian government's Electronic-Based Government Systems policy initiated in 2018, which significantly increased digital signature adoption across 652 government agencies and 989 integrated applications. Using the Prophet algorithm, we analyzed time-series data of digital signature transactions that exhibit strong seasonal patterns influenced by weekends, holidays, and special events. The methodology combined experimental research with the CRISP-DM framework, incorporating hyperparameter tuning to optimize forecasting accuracy. Key parameters included changepoint prior scale (0.5), seasonality prior scale (0.1), and holiday effects. Results revealed distinct transaction patterns: weekly peaks on Fridays (averaging 500,000 transactions), significant drops on weekends (<100,000 transactions), and notable fluctuations during policy implementation periods. The forecasting model achieved a Mean Absolute Percentage Error (MAPE) of 0.67, indicating moderate accuracy that warrants further refinement. This research contributes to the field of digital government by offering the first comprehensive analysis of digital signature transaction patterns in Indonesian public sector operations. It highlights the practical application of time-series forecasting for public service optimization and lays the groundwork for future studies on predictive modeling in e-government systems.

KEYWORDS *Digital Signature, Electronic-Based Government Systems, Prophet Algorithm, Seasonality, Infrastructure Resource Allocation.*

INTRODUCTION

Signature has existed in human creations for several millennia ago and has been used as a tool to authenticate and identify the identity since the era of the Sumerians and the Chinese in 2000 -- 3000 BC (Hamilton, 1967). At that time the method used was to create a seal and put it on the wax. As time goes by and with rising human literacy rates, the signature has changed into the form written on paper as we know it today. In 1677, the English Parliament issued the Statute of Frauds Act and introduced signatures as a tool to provide legality which was first applied to contractual documents (Huber & Headrick, 1999).

The emergence of information technology has affected the need for signatures on an electronic document (Penubadi et al., 2023). The idea was first presented in 1976 in a mathematical scheme that can be proven to fulfill the aspects needed to create a signature on electronic information (Kallam, 2015). The electronic signatures were actually implemented in 2000, after the issuing of the E-Sign Act by President Bill Clinton in the US (Zemnick, 2000). In Indonesia, signatures on electronic documents were legally recognized in 2016 through the issuing of the Act on Information and Electronic Transactions.

Since the passage of Presidential Regulation Number 95 of 2018 on Electronic-Based Government Systems (*Sistem Pemerintahan Berbasis Elektronik* or SPBE), the Indonesian government has been charged with expediting the development of digital transformation in government services (Yulianto et al., 2021). This regulation aims to establish an integrated, interoperable, and efficient digital bureaucracy (Hastuti & Suryanto, 2020). As a result, the implementation of electronic signatures has become increasingly common in government services, including licensing, civil registration, taxation, and administrative functions (Siregar et al., 2021). The use of electronic signatures not only increases service efficiency but also enhances transparency and data security (Mulyana et al., 2022). According to the National Cyber and Crypto Agency (BSSN), by January 2023, nearly 1,000 applications had incorporated electronic signatures with digital certificates issued by BSSN (BSSN, 2023). These certificates are now used across more than 600 government agencies, from ministries and state institutions to local governments (Wijaya et al., 2022). Studies emphasize that the adoption of Public Key Infrastructure (PKI)-based digital signatures is crucial for ensuring authentication and non-repudiation in digital public services (Rahim & Aziz, 2021). Additionally, the success of SPBE initiatives relies heavily on organizational readiness and the maturity of digital infrastructure in each agency (Tanuwidjaja & Kartika, 2023).

This research focuses on studying the characteristics of working patterns by government employees with indicators from the number of documents signed electronically. This research also studies the creation of electronic signature transaction forecasting models. This topic has never been conducted before; several previous research examined forecasting (Gañán et al., 2015) or statistical studies (Ganan et al., 2012) in the certificate revocation process.

The model will be built using the FBProphet algorithm. FBProphet was chosen because it can map trends and seasonality and is very suitable for use for data with repetitive characteristics (Sharma et al., 2022). Apart from that, the FBprophet algorithm is considered capable of producing predicted values that are close to real conditions from actual data (Zhu et al., 2021), this algorithm can also produce impressive results for several datasets (Shamshad et al., 2023). The forecasting model that has been built will then be evaluated using several error metric methods, such as Mean Absolute Deviation (MAD), Mean Square Error (MSE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE).

Previous research has explored aspects of digital signatures and forecasting, but gaps remain. For instance, Gañán et al. (2015) focused on revocation forecasting in public-key infrastructures, providing insights into certificate lifecycle management but not addressing transaction volume trends. Similarly, Sharma et al. (2022) applied the FB-Prophet algorithm for time series forecasting, demonstrating its robustness in handling seasonal patterns, though their study did not specifically target digital signature transactions in government contexts. This research fills these gaps by leveraging the FB-Prophet algorithm to analyze and forecast digital signature transaction trends in the Indonesian government, incorporating seasonal and holiday effects unique to this dataset.

The objectives of this study are twofold: (1) to analyze the characteristics of digital signature transactions in the Indonesian government, identifying patterns and fluctuations, and (2) to develop a forecasting model that can predict future transaction volumes, aiding in infrastructure planning and improving user experience. The findings will provide actionable insights for policymakers and IT administrators, ensuring efficient resource allocation and enhanced service delivery in electronic-based government systems.

RESEARCH METHOD

This research was conducted using a combination of two methodologies, namely experimental methodology (Thompson & Panacek, 2006) and Cross-Industry Standard Process for Data Mining (CRISP-DM). The experimental research technique adheres closely to scientific study design, which includes variables that can be measured, computed, and compared, as well as hypotheses and variables that researchers can change. Experiments are carried out in a controlled setting. Determining the link between two variables the dependent and independent variables is the goal of experimental research. Once the experimental research study is finished, a correlation analysis is done to see whether or not specific elements and the variables under examination are supported.

The CRISP-DM paradigm is divided into five stages: business comprehension, data preparation, modeling, evaluation, and deployment. The experimental methodology was carried out in the modeling and evaluation phases. Each phase in the CRISP-DM model consists of several activities and each activity uses its respective methods and techniques and will produce an artifact. The following is an explanation of each stage that will be carried out in this research:

The problems raised in this research depart from field observations and interviews. The problem faced in the organization is the unpredicted fluctuations that occur due to the increase in signature transactions which contribute to several incidents and impact on business continuity. The organization was unable to predict the increase in signature transactions, so the available capacity was failed to accommodate a significant increase in transactions. The organization can mitigate this risk if they can predict spikes in transactions and take preventative action by increasing resource capacity.

Problems that have been defined are then translated into data mining solutions. At this stage, the writer tries to find the right solution to predict fluctuations in digital signature transactions. The analytical approach used is by conducting descriptive and predictive analysis.

Data used in this research is an electronic signature transaction captured from March 18, 2021, until December 10, 2022. The transactions are carried out by 652 government agencies with a total of 989 integrated applications. The data that has been collected is then checked for quality by looking at the completeness of the data. The lack of data is because there are several national events or because several incidents have occurred. After correcting the data, then exploratory data analysis was carried out to obtain initial knowledge about the data used.

The experiments carried out in this study occurred in the phase of model training and evaluation. The purpose of the experiment is to find the right combination of hyperparameter settings that can produce a model with the best accuracy value. This study has several experimental variables: the dependent variable and the independent variable. The dependent variable will be the reference for the success criteria in the experimental process. The dependent variable used in this study is the result of measuring the accuracy value generated by the model that has been built. The manipulated independent variables are hyperparameter settings in the algorithm, such as holiday effect, seasonality in daily, weekly, and monthly, and changepoints. The algorithm that will be tested in the experiment is FBProphet. Trend, seasonality, and holidays are the three primary components of Prophet's decomposable time series model. The following equation combines them:

$$y(t) = g(t) + s(t) + h(t) + \epsilon_t \quad (1)$$

Here, s(t) denotes periodic changes (such as weekly and annual seasonality), h(t) denotes the effects of holidays that occur on possibly irregular schedules over one or more days, and g(t) is the trend function that simulates non-periodic variations in the time series value. Any idiosyncratic changes that the model is unable to account for are represented by the error term ϵ_t; we shall later assume parametrically that ϵ_t is normally distributed (Taylor & Letham, 2017). expansion trend models from Prophet can be used to model population expansion in natural environments. In its most basic form, the logistic growth model is commonly used to simulate this kind of growth.

$$g(t) = \frac{C}{1+\exp\left(-k(t-m)\right)} \quad (2)$$

Where m is an offset parameter, k is the growth rate, and C is the carrying capacity. Because business time series depict human actions, they frequently exhibit multi-period seasonality. For example, a 5-day workweek might have weekly recurring impacts on a time series, and school breaks and vacation schedules can have annual recurring effects. We need to define seasonality models that are periodic functions of t in order to fit and predict these effects. Prophet offers a versatile model of periodic effects by utilizing the Fourier series. Let P be the regular period that we anticipate the time series to have (for example, when we scale our time variable in days, P=365.25 for annual data or P=7 for weekly data). We can approximate arbitrary smooth seasonal effects with.

$$s(t) = \sum_{n=1}^{N}\left(a_n \cos\left(\frac{2\pi nt}{P}\right) + b_n \cos\left(\frac{2\pi nt}{P}\right)\right) \quad (3)$$

The model that has been built will be tested for accuracy using several accuracy measurement tools, MAD, MSE, RMSE, and MAPE. Numerous combinations of experiments are conducted as part of the testing procedure. The error value that results from the discrepancy between the actual and anticipated values can be used to gauge the accuracy of the prediction model; the lower the error value, the better the predictive model's performance.

RESULT AND DISCUSSION

Exploratory data analysis is carried out on electronic signature transactions which has been pre-processed into other formats to make it easier to gain insight into various data characteristics. The new data format is aggregation daily, monthly, day of the week, and day of the month. From the data that has been processed, it is known that the highest number of transactions exceeds one million transactions, while the lowest daily transactions, down to zero transactions, occur on several national holidays, the average daily number is 235,000 transactions. Fig. 1 shows the number of daily transactions. From this graph we can visually see the movement of daily transaction data. There is a decrease in numbers that can be seen periodically occurring in weekly periods which will be more clearly seen in Fig. 3. From this graph it can also be seen that high transactions occurred in the period July to November 2021. To find out why this happened, it is necessary to look for additional information such as the situation and conditions that occurred at that time, which could influence the working mechanisms of Government Employees. In 2021, the government will still implement several restrictive policies on employee activities, so the need to sign electronically is higher compared to 2022.

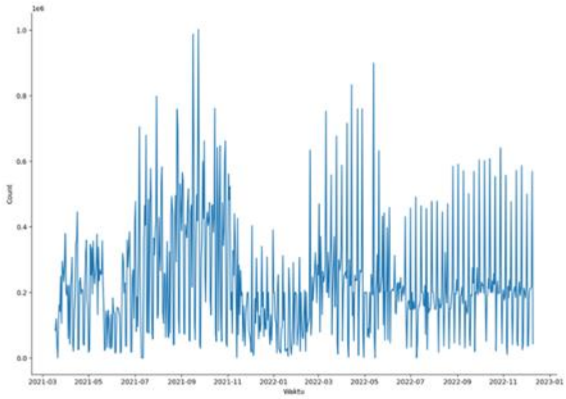

Figure 1. Daily Transaction Graph

Source: Processed from Indonesian government digital signature transaction data (2021–2022)

The graph in Fig. 2. shows the distribution of the number of signatures on the names of days. High transactions occur on Thursdays, but the intensity does not occur often. The highest average number of transactions is on Friday, namely 500.000 transactions. The lowest average transactions occur on Saturdays and Sundays, namely below 100.000 transactions. The average signature on other days ranges from 300 to 300. 400 thousand transactions. The graph in Fig. 3. also shows transaction data for each day. The graph depicts the movement of the number of transactions on that day at any time. The movement of signature transactions on Saturday and Sunday is very similar and quite consistent. Movements on other days, fluctuations are difficult to predict.

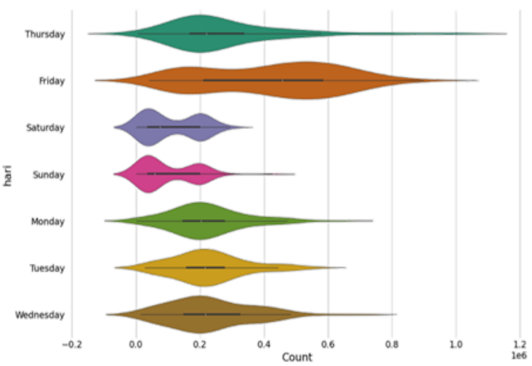

Figure *2*. Distribution of Number of Signatures for Days

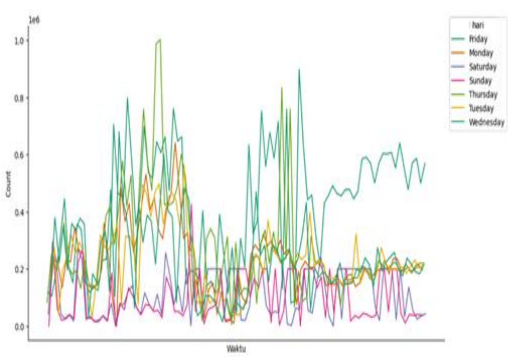

Figure *3*. Movement of Number of Signatures on Each Day by Time

Source: Aggregated from daily transaction records of 652 government agencies (2021–2022)

Source: Analyzed from timestamped transaction logs provided by BSSN (2021–2022)

Next, we use FBProphet to extract trend values from signature transaction data. This algorithm is also used to create a forecasting model, to predict the number of transactions in the future. The model that has been built is then measured using several error metric methods. The first graph in Figure 4 shows that the movement of signature transactions rose high in the third quartile of 2021 and decreased at the beginning of 2022. It rose again in the second quartile and moved steadily in the following time. Then from the second graph, it can be seen that high transactions often occur on Fridays, while on Saturdays and Sundays, the number of transactions looks low. From the last graph in Fig. 4., it can be seen that high transactions often occur in the third week, while on other days the fluctuation pattern is difficult to see.

In this research, we conducted experiments with the hyperparameter tuning method. Table 1 shows some of the control parameters that were used. Points of change Range is the percentage of history where the trend is permitted to veer off course. The trend's flexibility, specifically how much it shifts at trend changepoints, is measured by the Changepoint Prior Scale. The following are the ideal parameters to employ while creating a forecasting model: Changepoints: 10, Seasonality Prior Scale: 0.1, Holidays Prior Scale: 0.01, Changepoint Prior Scale: 0.5, Changepoint Range: 0.8 Seasonality is false on a daily basis, weekly, and annual basis. By setting these parameters, the best accuracy values obtained are as follows. MAE: 89305, MSLE: 0.53 and MAP E: 0.67. The resulting accuracy figures can be said to be not good and need to be re-examined using different methods and algorithms. The red scatter graph seen in Figure 6 is the real value, while the blue line graph is the predicted value. It can be seen that there are several gaps or quite large error values in the graph.

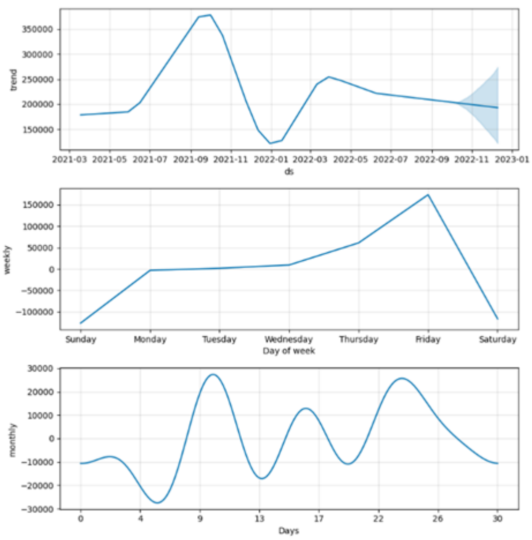

Figure 4. Electronic Signature Transaction Trends Chart

Source: FB-Prophet algorithm output applied to government transaction data (2021–2022)

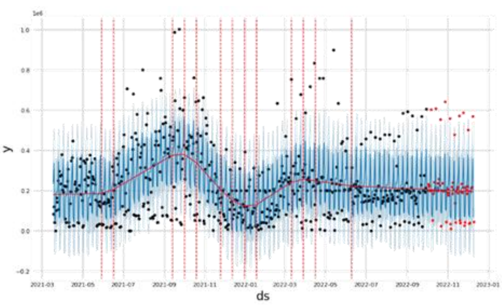

Figure 5. Line graph of FBProphet forecasting model

Source: Model validation results using Prophet (Taylor & Letham, 2017) on test dataset

Table 1. Variable Experiment

No	Parameter	Values
1	Changepoints	[1, 5, 10, 25]
2	Changepoint Prior Scale	[0.001, 0.01, 0.1, 5]
3	Changepoint Range	[0.8, 0.95]
4	Seasonality Prior Scale	[0.01, 0.1, 1, 10]
5	Holidays Prior Scale	[0.01, 1, 7, 10]
6	Daily Seasonality	[True, False]
7	Yearly Seasonality	[True, False]
8	Weekly Seasonality	[0, 5, 10]

Source: Hyperparameter tuning configurations for Prophet algorithm (this study)

CONCLUSION

This research explores digital signature transactions by government employees across various sectors, including population services, citizenship administration, business licensing, government administration, and health, using the number of signed documents as an indicator of employee productivity and work patterns. The study developed a forecasting model employing the FBProphet algorithm with hyperparameter tuning, achieving a Mean Absolute Percentage Error (MAPE) of 0.67. While this indicates moderate accuracy, it suggests the need for further improvement. Future research should investigate alternative forecasting algorithms tailored to the specific data characteristics and consider additional relevant variables, such as user growth, information system categories, and government sector classifications, to enhance prediction accuracy and provide deeper insights into digital signature transaction dynamics.

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