Journal of Actuarial, Finance and Risk Management (JAFRM)
Vol. 2(1), June, 2023.

Forecasting the Monthly Stock Price per Share of Taiwan Semiconductor Manufacturing Company Limited (TSMC) using ARIMA Box-Jenkins Method

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Abstract— The Taiwan Semiconductor Manufacturing Company Limited, commonly known as TSMC, is a Taiwanese multinational corporation specializing in the manufacturing and designing of semiconductors under contract. People can buy Stocks from Taiwan Semiconductor Manufacturing Company Limited. Stocks are one of the attractive investment instruments for companies and individuals. There are some theories and analyses to predict stock prices to help investors make wiser decisions when buying and selling stock portfolios. In this study, researchers will use ARIMA(p,d,q) technical analysis to predict the stock price of Taiwan Semiconductor Manufacturing Company Limited for the next 5 months from January 1, 2005 to May 1, 2005. For this forecasting, researchers used Taiwan Semiconductor Manufacturing Company Limited historical stock price data from January 1, 1998 to December 31, 2004 that was obtained from the Yahoo Finance website. Based on the test results of 8 ARIMA models, the best model that researchers got is model 2 ARIMA (2,1,1) with the equation $Y_t = 0.0759\,Y_{t-1} + 0.2706\,Y_{t-2} + e_t - 0.198e_{t-1}$. This model is considered to be the best because it has the smallest MSE Value, which is 0.1076018; the smallest RMSE value, which is 0.0301156; the smallest MAE value, which is 0,2495926; and the smallest MAPE value, which is 3.0116%. This study shows that the stock price is predicted to rise for the next 5 months from January 1, 2005 to May 1, 2005.

Keywords— semiconductor manufacturing company, ARIMA, forecasting, stationary, time series analysis

I. INTRODUCTION

A stock that is referred to as equity, is a financial instrument signifies partial ownership in a company. These ownership stakes ate known as “shares,” entitling shareholders to a proportionate claim on the company’s assets and profits based on the amount of stock they process [1, 2]. Shareholders are individuals who possess the ability to purchase and retain shares in a company, thereby assuming ownership. On the other hand, an investor refers to someone who invests funds into a business that has not issued shares [3]. Investors engage in stock purchases for diverse motives, including capital appreciation, which materializes when the stock price increases. They also seek dividend payments, which are disbursed by the company to shareholders from its earnings. Additionally, investors value the opportunity to possess voting shares and exert influence over the company's decisions [4].

Two primary types of stocks exist, namely common stock and preferred stock. Common stock grants owners the privilege to vote during shareholder meetings and receive dividends. Conversely, preferred stockholders generally lack voting rights but are entitled to receive dividend payments before common stockholders. They also hold precedence over common stockholders in the event of the company's bankruptcy and asset liquidation. Nevertheless, individuals have the opportunity to engage in buying and selling stocks through various channels, such as a direct stock plan, a dividend reinvestment plan, a discount or full-service broker, and a stock fund. There are some theories and analyses to predict stock prices to help investors make wiser decisions when buying and selling stock portfolios. ARIMA(p,d,q) is one of the analyses methods to predict stock prices [4].

In this study, researchers will use ARIMA(p,d,q) technical analysis to predict the stock price of Taiwan Semiconductor Manufacturing Company Limited for 5 months from January 1, 2005 to May 1, 2005. For this forecasting, researchers used Taiwan Semiconductor Manufacturing Company Limited historical stock price data from January 1, 1998 to December 31, 2004 that was obtained from the Yahoo Finance website [5].

The researcher has chosen to utilize Taiwan Semiconductor Manufacturing Company Limited (TSMC) due to its status as a prominent Taiwanese multinational semiconductor manufacturer. TSMC is widely recognized for being one of the largest independent foundries worldwide, with a specialized focus on producing integrated circuits (ICs) and system-on-chips (SoCs). To fulfil the researcher's objective of employing the ARIMA Box-Jenkins method, previously gathered data pertaining to TSMC from January 1, 1998, to December 31, 2004 will be utilized. The decision to use older data is driven by the researcher's requirement for TSMC data compatible with the ARIMA Box-Jenkins methodology. The researchers opted to forecast the future stock price of TSMC over a period of five months, specifically from January 1, 2005, to May 1, 2005. The objective of the researcher is to ascertain whether the stock will undergo an upward or downward trend. The researchers aim to evaluate the extent to which these forecasts correspond with the actual results observed in the market.

In regards to the anticipation of weak smartphone demand in the first half of 2023, Rob Starks Jr provided an explanation and suggested that TSMC presents an excellent long-term investment opportunity. He praised TSMC as a superior chip manufacturer, highlighting its status as the largest global semiconductor contract manufacturer (also known as a foundry). According to Trend Force, a market research firm, TSMC expanded its share of the foundry market to 56.1% in the third quarter of 2022. In comparison, Samsung, holding the second position, experienced a decline of 10 basis points, bringing its market share to 15.5 [6].

In the third quarter, Taiwan Semiconductor Manufacturing (TSMC) demonstrated remarkable revenue growth of 35.9% compared to the previous year, reaching $20.23 billion. However, what sets TSMC apart is its exceptional profit margins. According to Intel CEO Pat Gelsinger, a semiconductor company considered "best in class" achieves gross margins around 60% and operating margins around 40%. Despite challenging economic conditions, TSMC surpassed these benchmarks in the third quarter of 2022. It achieved a gross margin of 60.4%, surpassing its projected range of 57.5% to 59.5% and exceeding the gross margin of 51.3% from the previous year. Additionally, TSMC achieved an outstanding operating margin of 50.6%, surpassing its guidance of 47% to 49% and exceeding the operating margin of 41.2% from the previous year [6].

Historically, semiconductor companies that lead the race in producing smaller and more power-efficient chips gain advantages such as premium pricing, increased revenue, and higher profit margins. TSMC is currently leading this race. As the size and complexity of chips decrease, substantial investment in research and development and capital expenditure becomes necessary to produce chips capable of commanding premium prices. Moreover, due to the cyclical nature of the chip industry, only the largest and most stable companies can afford the high costs associated with cutting-edge chip development. Consequently, TSMC is one of the few companies at the forefront of creating the smallest semiconductors, alongside Samsung [6].

II. METHODOLOGY

A. *Box-Jenkins Method*

Autoregressive Integrated Moving Average (ARIMA) models have wide-ranging applications in various industries, particularly in demand forecasting for sectors like food manufacturing. ARIMA models are part of a broader category of models used to predict time series data. They are commonly denoted as ARIMA (p, d, q), where p represents the order of the autoregressive model, d signifies the degree of differencing, and q indicates the order of the moving-average model. By applying differencing, ARIMA models transform non-stationary time series into stationary ones, enabling the estimation of future values based on historical data. These models leverage auto-correlations and moving averages of residual errors in the data to forecast forthcoming values [10]. The Box-Jenkins Model, created by mathematicians George Box and Gwilym Jenkins, is a mathematical framework employed for forecasting data ranges using inputs from a given time series. This model possesses the ability to analyze different types of time series data in order to facilitate predictions. Its methodology involves examining the discrepancies between data points to ascertain future outcomes. By utilizing techniques like autoregression, moving averages, and seasonal differencing, the model identifies patterns and generates forecasts. Box-Jenkins Models are utilized in predicting a wide array of data points or data ranges, including business data and future security prices [12].

1) Autoregressive (AR)

An autoregressive model is a regression model where previous values of the dependent variable (y) up to a specific lag (p-th time in the past) are used as predictors [10]. Here, Y_t : Time series data refers to the data where the variable of interest is observed or measured as the response variable at a specific time point, denoted as t ; $Y_{t-1}, Y_{t-2} + \cdots + Y_{t-p}$: time series data to t-1, … , t-p ; $\emptyset_1, \emptyset_2, \ldots, \emptyset_p$: autoregressive parameters ; and e_t : error value at time t

$$\boldsymbol{Y_t = \emptyset_1 Y_{t-1} + \emptyset_2 Y_{t-2} + \cdots + \emptyset_p Y_{t-p} + e_t} \tag{15}$$

2) Moving Average (MA)

A moving average model applies a model similar to regression to past forecast errors [10]. Here, $\theta_1, \theta_2, \ldots, \theta_q$: moving average parameter and $e_1, e_2, \ldots, e_{t-q}$ = error value at time series t, t-1, … , t-q.

$$\boldsymbol{Y_t = e_t - \theta_1 e_{t-1} + \theta_2 e_{t-2} - \cdots - \theta_q e_{t-q}} \tag{16}$$

3) Autoregressive Integrated Moving Average (ARIMA)

An ARIMA model can be seen as an ARMA model applied to a time series that has been differenced d times, resulting in a stationary differenced time series [10]. A time series $\{Y_t\}$ is considered to conform to an integrated autoregressive moving average (ARIMA) model when the *d*th difference, denoted as $W_t = \nabla^d Y_t$, represents a stationary autoregressive moving average (ARMA) process. If $\{W_t\}$ follows an ARMA(*p*,*q*) model, we refer to $\{Y_t\}$ as an ARIMA(*p*,*d*,*q*) process. Fortunately, in practical scenarios, we often find that d can typically be set to 1 or, at most, 2 [11]. Summary of all steps in forecasting by using ARIMA model is illustrated by a flow chart at Figure 1

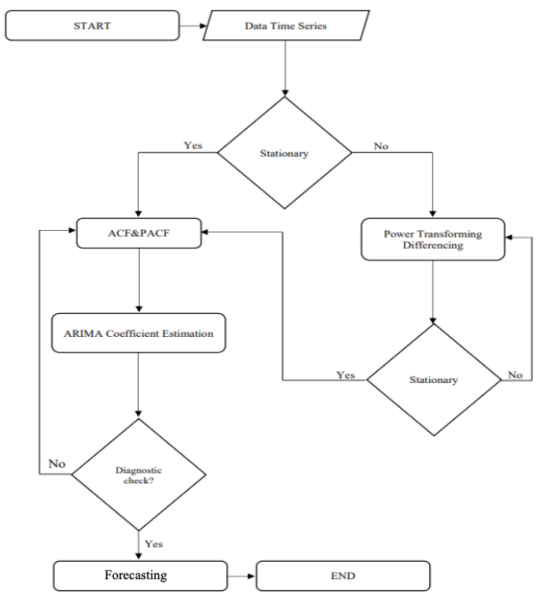

Figure 1. ARIMA Box-Jenkins Flowchart

III. RESULT AND DISCUSSION

A. Data Preparation

The data used is Taiwan Semiconductor Manufacturing Company Limited Monthly data from January 1, 1998 to December 31, 2004 that was obtained from the Yahoo Finance website.

TABLE 1
TAIWAN SEMICONDUCTOR MANUFACTURING COMPANY LIMITED DATA, 1998-2004

Date	Close	Date	Close	Date	Close
1998-01-01	5.048224	2000-12-01	8.370419	2003-11-01	8.772676
1998-02-01	6.097723	2001-01-01	11.713734	2003-12-01	8.264232
1998-03-01	5.499907	2001-02-01	9.137101	2004-01-01	9.022863
1998-04-01	5.220926	2001-03-01	9.462213	2004-02-01	8.38529
1998-05-01	4.01201	2001-04-01	11.762258	2004-03-01	8.425643
1998-06-01	3.586896	2001-05-01	9.6369	2004-04-01	7.691224
1998-07-01	3.905731	2001-06-01	10.319149	2004-05-01	8.191598
1998-08-01	3.274703	2001-07-01	11.073215	2004-06-01	7.645545
1998-09-01	3.77554	2001-08-01	8.817812	2004-07-01	6.550695
1998-10-01	4.603847	2001-09-01	6.446921	2004-08-01	6.946313
1998-11-01	4.62311	2001-10-01	8.770258	2004-09-01	6.569096
1998-12-01	4.372692	2001-11-01	10.82186	2004-10-01	6.964714
1999-01-01	6.164147	2001-12-01	11.664239	2004-11-01	7.332731
1999-02-01	6.010044	2002-01-01	11.528372	2004-12-01	7.811152
1999-03-01	7.281399	2002-02-01	11.039248		
1999-04-01	7.396977	2002-03-01	14.09627		
1999-05-01	8.07118	2002-04-01	12.024289		
1999-06-01	10.47905	2002-05-01	11.26343		
1999-07-01	9.573691	2002-06-01	9.714538		
1999-08-01	10.970063	2002-07-01	6.815122		
1999-09-01	11.183304	2002-08-01	6.105214		
1999-10-01	13.126166	2002-09-01	4.745178		
1999-11-01	13.576342	2002-10-01	5.843668		
1999-12-01	17.059277	2002-11-01	6.912268		
2000-01-01	19.665556	2002-12-01	5.268269		
2000-02-01	22.674623	2003-01-01	5.006724		
2000-03-01	21.608418	2003-02-01	5.29816		
2000-04-01	19.831409	2003-03-01	5.111342		
2000-05-01	17.135096	2003-04-01	6.254668		
2000-06-01	18.712132	2003-05-01	7.57734		
2000-07-01	14.739216	2003-06-01	7.532503		
2000-08-01	16.983458	2003-07-01	8.070539		
2000-09-01	9.917127	2003-08-01	9.507095		
2000-10-01	11.00892	2003-09-01	8.740394		
2000-11-01	8.158126	2003-10-01	8.926017		

B. *Stationarity Check*

Prior to utilizing the data, it is essential to assess its stationarity using the Augmented Dickey-Fuller Test method in R Studio. If the p-value of the data is below 0.05, it can be considered stationary. In Figure 2, we observe that the p-value obtained from the Augmented Dickey-Fuller Test is 0.3418. This value exceeds the threshold of 0.05, indicating that the data is non-stationary.

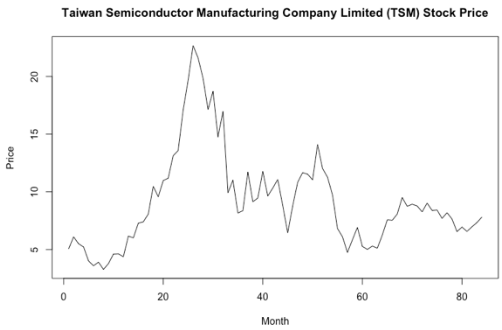

Figure 2. Before Differencing

To make this data stationary, we have to differencing the data. As we can see in the Figure 3, the p value from Augmented Dicky Fuller Test is 0.03816. This number is less than 0.05. Therefore, we can conclude that the data already stationary.

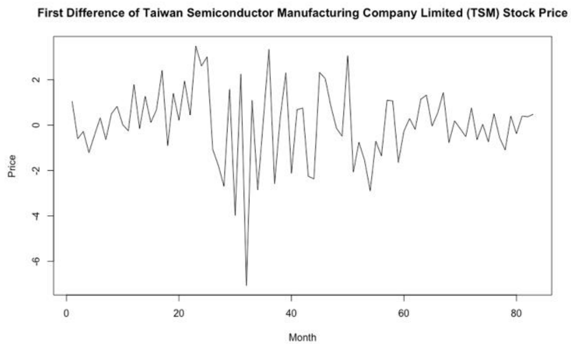

Figure 3. After first differencing

C. *Model Specification*

By employing RStudio, the model specification can be determined through the selection of p (representing the order of the autoregressive component) and q (representing the order of the moving average component). Figure 4 depicts the plot for the autocorrelation function (ACF), while Figure 5 illustrates the plot for the partial autocorrelation function (PACF).

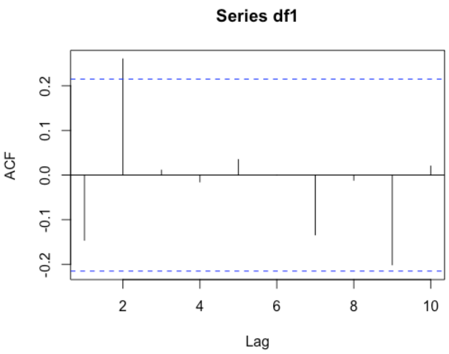

Figure 4. ACF Plot

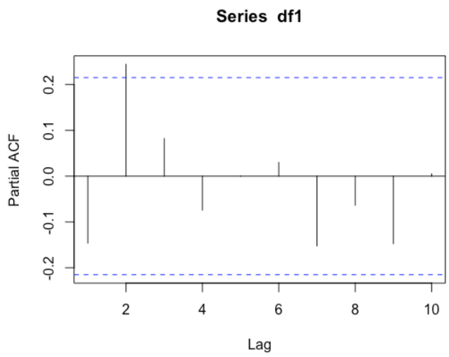

Figure 5. PACF Plot

Based on the information provided by Figure 4, we can observe that the ACF cuts off at a lag time of 2. Thus, the value of q is determined as 2. Similarly, Figure 5 indicates that the value of p is 2. As mentioned earlier, the differencing process was performed once, leading to a value of d equal to 1. Consequently, Table 2 presents a total of 8 ARIMA model specifications based on these parameters.

TABLE 2
ARIMA MODEL SPECIFICATION

No	Model ARIMA	p	d	q
1	(2,1,2)	2	1	2
2	(2,1,1)	2	1	1
3	(2,1,0)	2	1	0
4	(1,1,2)	1	1	2
5	(1,1,1)	1	1	1
6	(1,1,0)	1	1	0
7	(0,1,2)	0	1	2
8	(0,1,1)	0	1	1

Based on Table 2, there are 8 different specifications for the ARIMA models. With a value of 1 for q, 2 for p, and 1 for d, we can start with the ARIMA (2,1,2) model as the first one. Subsequently, we can create additional models by decreasing the value of q. The second ARIMA model would be ARIMA (2,1,1), and the third ARIMA model would be ARIMA (2,1,0). Since the third ARIMA has a q value of 0, we can decrease the value of p for the fourth model, resulting in ARIMA (1,1,2). Moving forward, we need to decrease the q value from 2 to 1 and then to 0. Consequently, the fifth ARIMA model becomes ARIMA (1,1,1), followed by the sixth model, ARIMA (1,1,0). Since we have previously utilized q values of 2 and 1, we must now utilize 0 as the q value. Consequently, the seventh ARIMA model is ARIMA (0,1,2), and the eighth ARIMA model is ARIMA (0,1,1).

D. *Parameter Estimation*

Through analysis by using RStudio, we obtain parameter estimations, encompassing metrics such as mean squared error (MSE), log-likelihood, and Akaike Information Criterion (AIC). These estimations are presented in Table 3 for reference.

TABLE 3
PARAMETER ESTIMATION FOR ARIMA MODEL

Model ARIMA	**Coefficient of Estimation Result**						
	AR1	AR2	MA1	MA2	MSE	Log likelihood	AIC
(2,1,2)	-0,1209	-0,0752	-0,0013	0,3441	4,604	-157,59	323,18
(2,1,1)	0,0759	0,2706	-0,198		2,624	-157,88	321,76
(2,1,0)	-0,1097	0,2406			2,635	-158,05	320,1
(1,1,2)	-0,0802		-0,0418	0,2786	2,606	-157,6	321,21
(1,1,1)	-0,6467		0,4856		2,739	-159,62	323,23
(1,1,0)	-0,1449				2,804	-160,57	323,14
(0,1,2)			-0,1147	0,2827	2,607	-157,63	319,26
(0,1,1)			-0,0962		2,825	-160,87	323,74

From this table we know that ARIMA (1,1,2) has the smallest MSE value. And ARIMA (0,1,2) has the smallest AIC value.

E. Residual Analysis

With the utilization of RStudio, the Shapiro test and Ljung-Box Test can be applied. The Shapiro test is employed as a statistical evaluation to ascertain whether the provided data adheres to a normal distribution. In this test, the null hypothesis assumes that the population follows a normal distribution. If the calculated p-value surpasses 0.05, the null hypothesis is deemed valid. Conversely, the alternative hypothesis suggests that the population does not conform to a normal distribution. If the obtained p-value is less than or equal to 0.05, the null hypothesis is rejected [13].

The Ljung-Box test, named after statisticians Greta M. Ljung and George E.P. Box, is a statistical test utilized to investigate the presence of autocorrelation within a time series. Its purpose is to verify that the p-value of the test is greater than 0.05. This result indicates that the residuals of our time series model are independent, which is a typical assumption made during the model development phase [14].

The outcomes of both tests for the models are displayed in Table 4. From the table, we observe that Model 7, ARIMA (0,1,2), exhibits the lowest AIC value, which is 319.26. However, this model does not pass the Shapiro Test. On the other hand, Model 2, Model 3, and Model 4 have slightly different AIC values compared to Model 7, but they do pass the test. As a result, one of these models could be considered the most suitable option.

TABLE 4
ARIMA MODEL RESIDUAL ANALYSIS RESULTS

Model ARIMA	Shapiro Test	Ljung-Box Test	AIC	Result
(2,1,2)	0,04134	0,9992	323,18	Not Passed
(2,1,1)	0,07334	0,963	321,76	Passed
(2,1,0)	0,0687	0,8493	320,1	Passed
(1,1,2)	0,05118	0,9908	321,21	Passed
(1,1,1)	0,03012	0,634	323,23	Not Passed
(1,1,0)	0,006068	0,7512	323,14	Not Passed
(0,1,2)	0,04667	0,9372	319,26	Not Passed
(0,1,1)	0,004747	0,8031	323,74	Not Passed

F. Forecasting

From Table 5, Table 6, and Table 7 we know that the Forecasting Value of the ARIMA (2,1,1), ARIMA (2,1,0), and ARIMA (1,1,2).

TABLE 5
FORECASTING VALUE OF THE ARIMA (2,1,1)

DATE	LOWER BOUND	UPPER BOUND	PREDICTED DATA	ACTUAL DATA
January 1, 2005	5,195043	10,52378	7,859412	8,47
February 1, 2005	4,447055	11,53802	7,992539	7,92
March 1, 2005	3,348318	12,68308	8,015701	7,8
April 1, 2005	2,504951	13,60202	8,053484	8,39
May 1, 2005	1,664405	14,46083	8,062619	8,05

TABLE 6
FORECASTING VALUE OF THE ARIMA (2,1,0)

DATE	LOWER BOUND	UPPER BOUND	PREDICTED DATA	ACTUAL DATA
January 1, 2005	5,177217	10,51722	7,847219	8,47
February 1, 2005	4,38346	11,53326	7,95836	7,92
March 1, 2005	3,254595	12,6551	7,954848	7,8
April 1, 2005	2,45528	13,50866	7,981971	8,39
May 1, 2005	1,64858	14,30772	7,978152	8,05

TABLE 7
FORECASTING VALUE OF THE ARIMA (1,1,2)

DATE	LOWER BOUND	UPPER BOUND	PREDICTED DATA	ACTUAL DATA
January 1, 2005	5,2211383	10,52158	7,866481	8,47
February 1, 2005	4,453879	11,52051	7,987195	7,92
March 1, 2005	3,279039	12,67599	7,977513	7,8

April 1, 2005	2,384508	13,57207	7,97829	8,39
May 1, 2005	1,611513	14,34494	7,978228	8,05

Based on the information provided in Table 5, Table 6, and Table 7, it can be inferred that the forecasting process is progressing favorably. To determine the best model, it is necessary to compare the error measures for forecasting using ARIMA (2,1,1), ARIMA (2,1,0), and ARIMA (1,1,2).

TABLE 8
ERROR MEASURES FOR FORECASTING USING ARIMA (2,1,1), ARIMA (2,1,0), AND ARIMA (1,1,2)

	ARIMA (2,1,1)	ARIMA (2,1,0)	ARIMA (1,1,2)
MSE	0,107601758	0,116991073	0,114983512
RMSE	0,030115601	0,03115632	0,032096661
MAE	0,2495926	0,2591732	0,2663418
MAPE	3,0116%	3,1156%	3,2097%

By examining Table 8, it is evident that the error value associated with ARIMA (2,1,1) is the lowest among the models considered. Hence, the ARIMA (2,1,1) model is deemed the most optimal. Referring back to Table 3, the model can be expressed in the form of the equation below

$$\boldsymbol{Y_t = 0.0759\, Y_{t-1} + 0.2706\, Y_{t-2} + e_t - 0.198 e_{t-1}} \quad (17)$$

The forecasting of stock price of Taiwan Semiconductor Manufacturing Company Limited for the next 5 months from January 1, 2005 to May 1, 2005 using ARIMA (2,1,1) is shown in Figure 6.

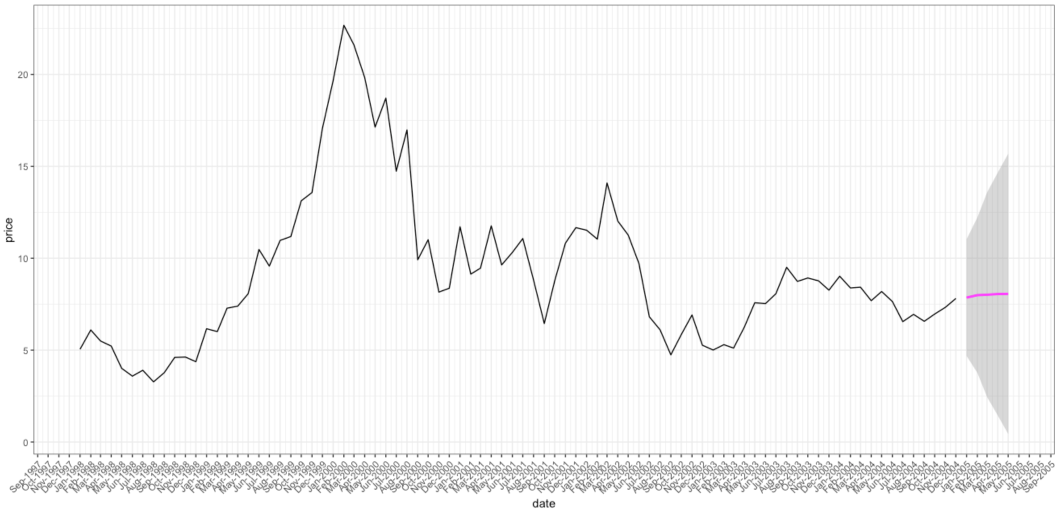

Figure 6. Forecasting using ARIMA (2,1,1)

IV. *CONCLUSION*

The forecasting of stock price of Taiwan Semiconductor Manufacturing Company Limited for the next 5 months from January 1, 2005 to May 1, 2005. The researchers used Taiwan Semiconductor Manufacturing Company Limited historical stock price data from January 1, 1998 to December 31, 2004 that was obtained from the Yahoo Finance website. In this study the researcher using ARIMA Box-Jenkins Method. The findings indicate that the ARIMA (2,1,1) model is the best, as evidenced by the following equation

$$Y_t = 0.0759\, Y_{t-1} + 0.2706\, Y_{t-2} + e_t - 0.198 e_{t-1}$$

This particular model demonstrates high quality as it exhibits the lowest error value of MAPE, which stands at 3.0116%. .

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