Peter the Great St. Petersburg Polytechnic University
Institute of computer science and cybersecurity
Higher school of artificial intelligence

Emergency department forecasting with hourly occupancy using time series analysis

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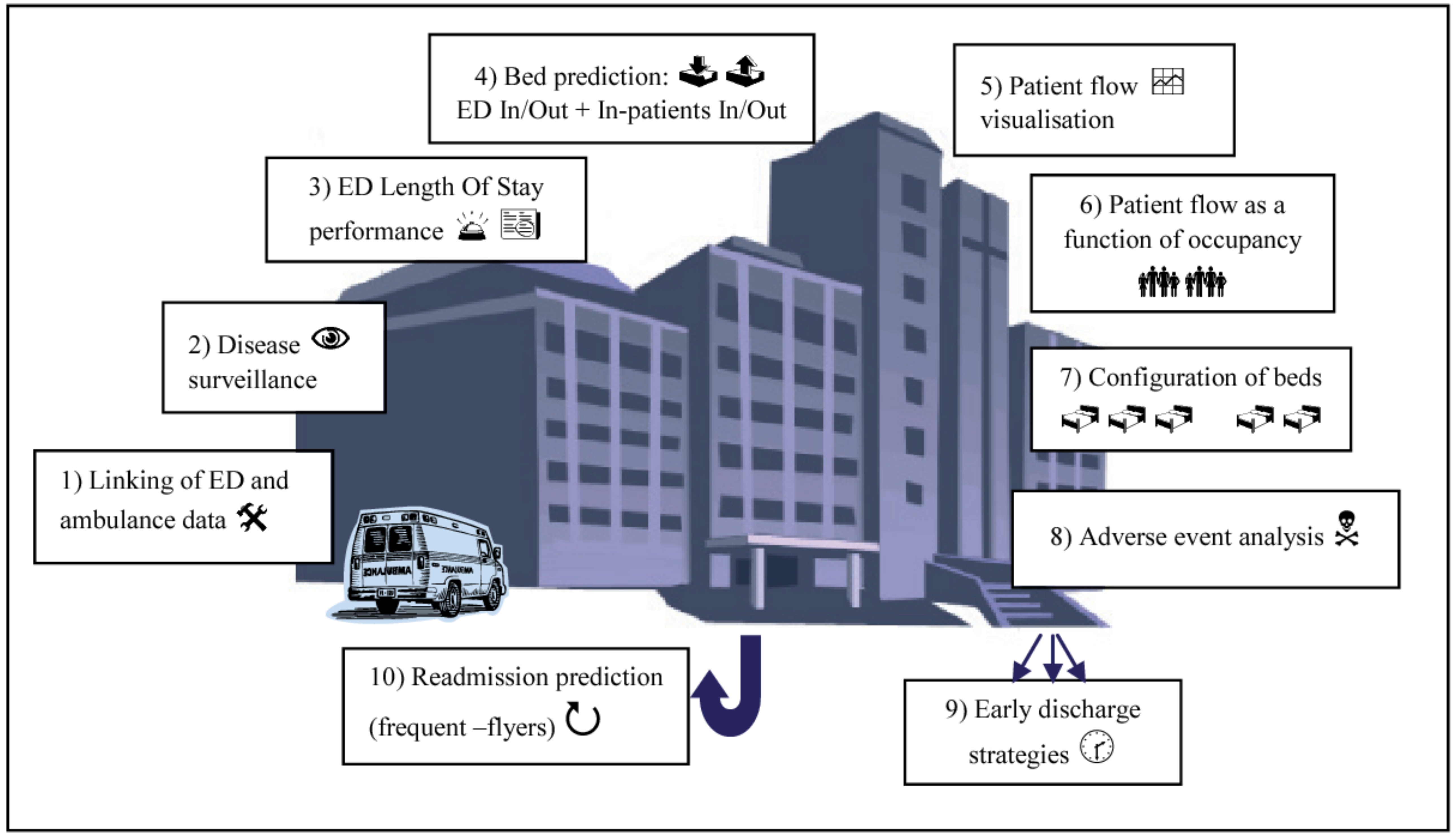
Introduction

Significance:

24-hour SARIMAX model enables real-time, hour-specific predictions for short-time forecasting in EDs.



Area of expertise:

- Hourly forecast
- ML methods
- Time series analysis

Problem statement

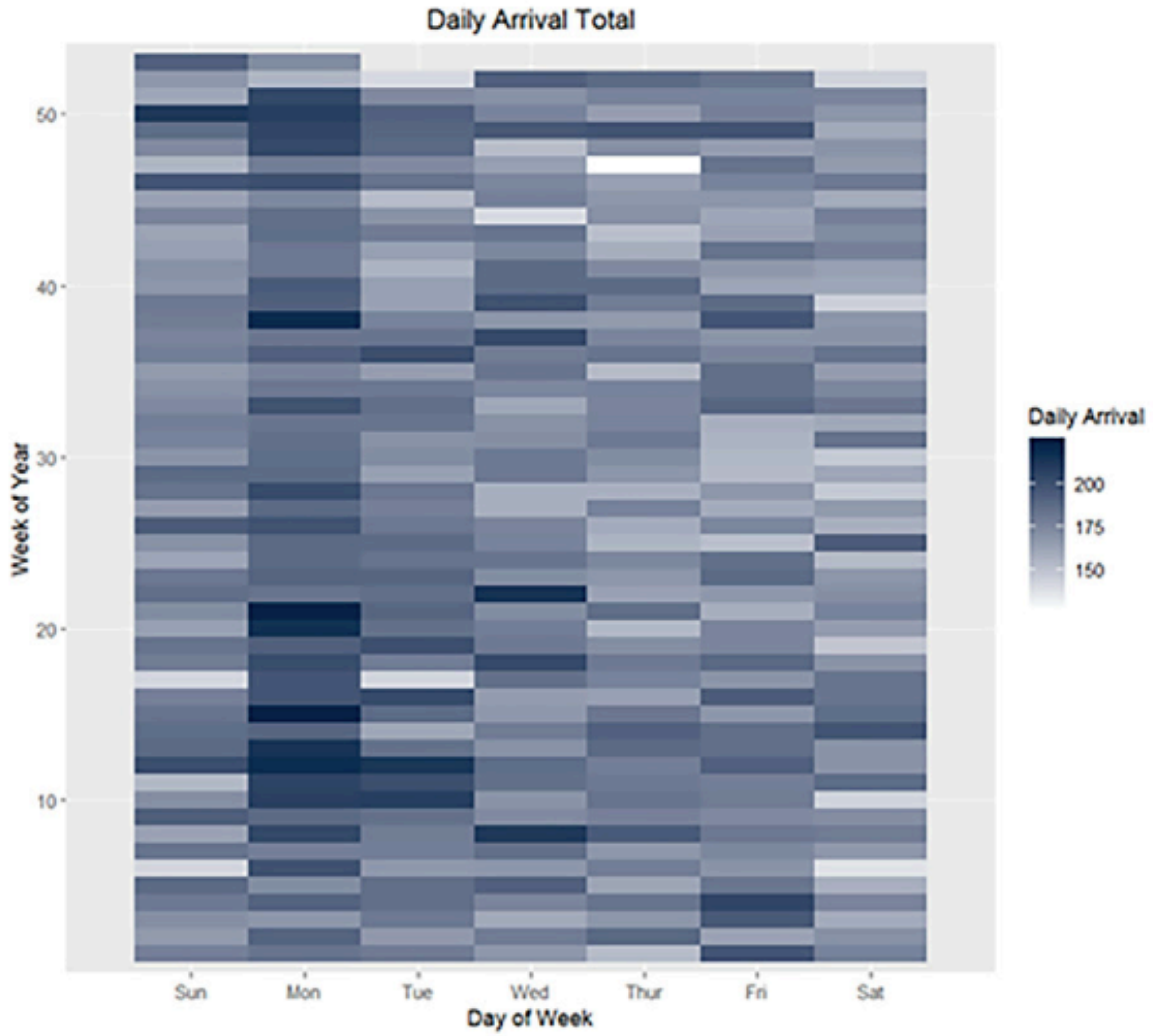
- The basic ARIMA model underperforming modern models in forecast accuracy.
- Not all ARIMA-based models can forecast in real-time.
- Classic models shows less accuracy in short-term forecast.
- Older versions cannot handle TSD.

Methods

Datasets

Real datas of hospital:

- Data source: an academic medical center with an ED, including 59 beds.
- Data volume: 65,132 ED visits
- Calendar variables



Methods

Approach

- Cross-validation to improve forecasting accuracy.
- Application of AIC criteria to determine model complexity and quality.
- Use of Ljung–Box tests to check the distribution of model residuals.
- Analysis of the impact of time and trends on forecasting accuracy.

$$\mathrm{AIC} = 2k - 2\ln\widehat{L}$$

Akaike criterion
k - |estimators|, L - max(likelihood)

$$\hat{\Gamma}_\ell = \frac{1}{T}\sum_{t=\ell+1}^{T}(r_t - \bar{r})(r_{t-\ell} - \bar{r})', \quad \ell \geq 0,$$

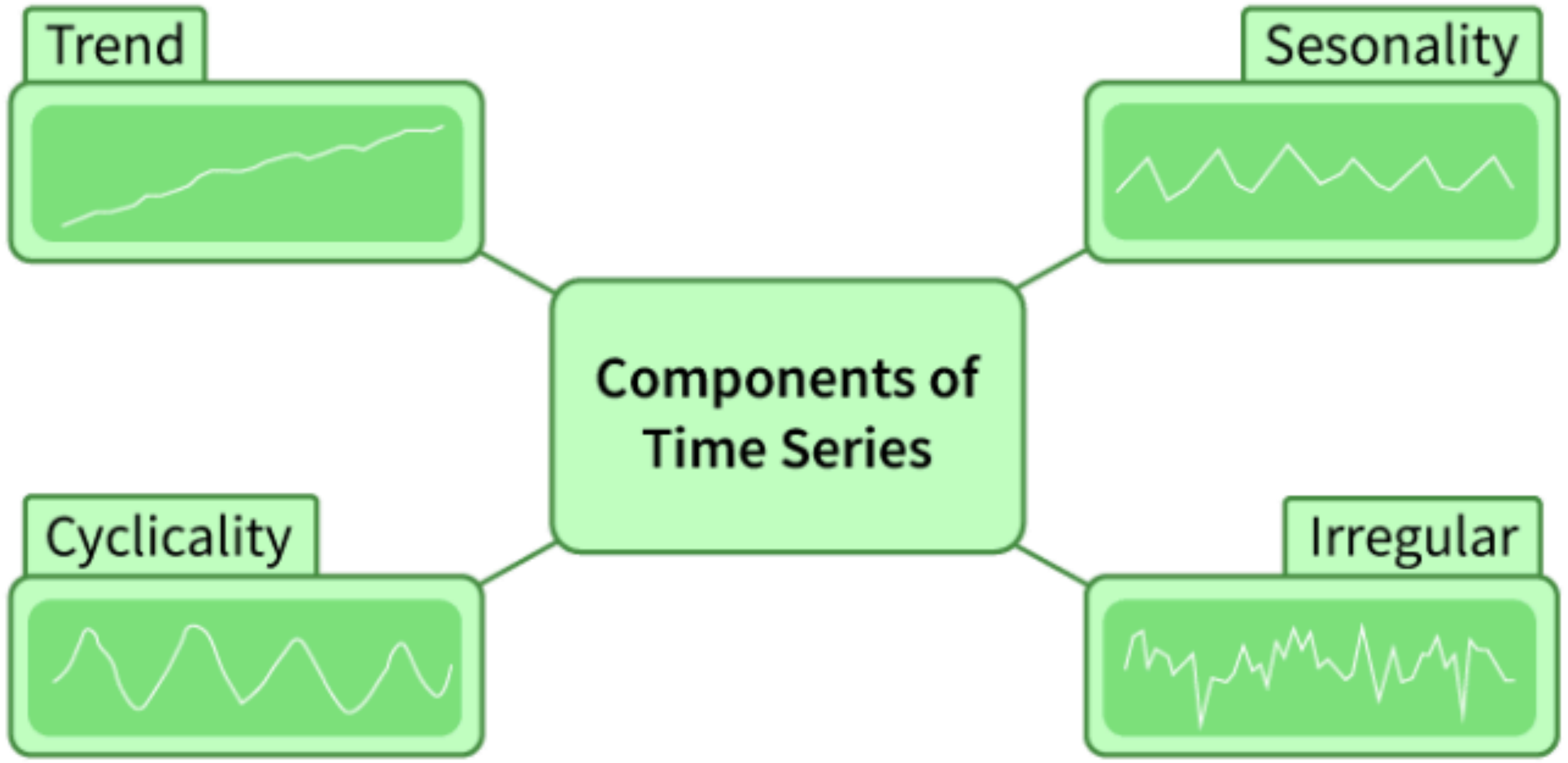
$$\hat{\rho}_\ell = \hat{D}^{-1}\hat{\Gamma}_\ell\hat{D}^{-1}, \quad \ell \geq 0, \qquad \bar{r} = \frac{\sum_{t=1}^{T} r_t}{T}$$

Ljung-Box test formula: autocovariance function with data $\{r_i | t = 1,\ldots,T\}$

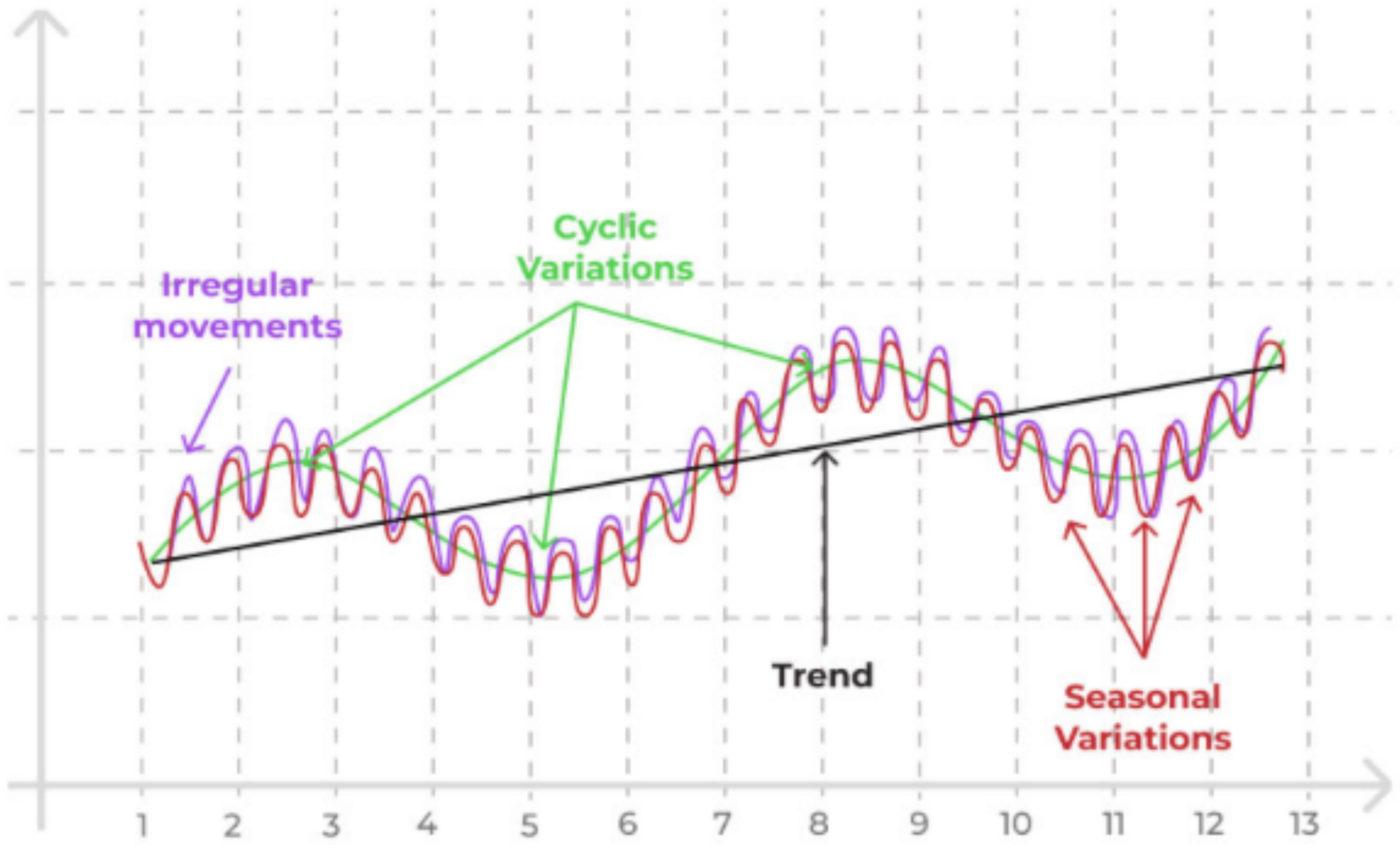
Methods

Approach

- Use of time series with real-time ED occupancy, severity index, and patient count as regressors.
- Model with seasonal regressors to account for time-of-day and day-of-week effects.
- Analysis of the impact of time and trends on forecasting accuracy.



TSD components



TSA graph

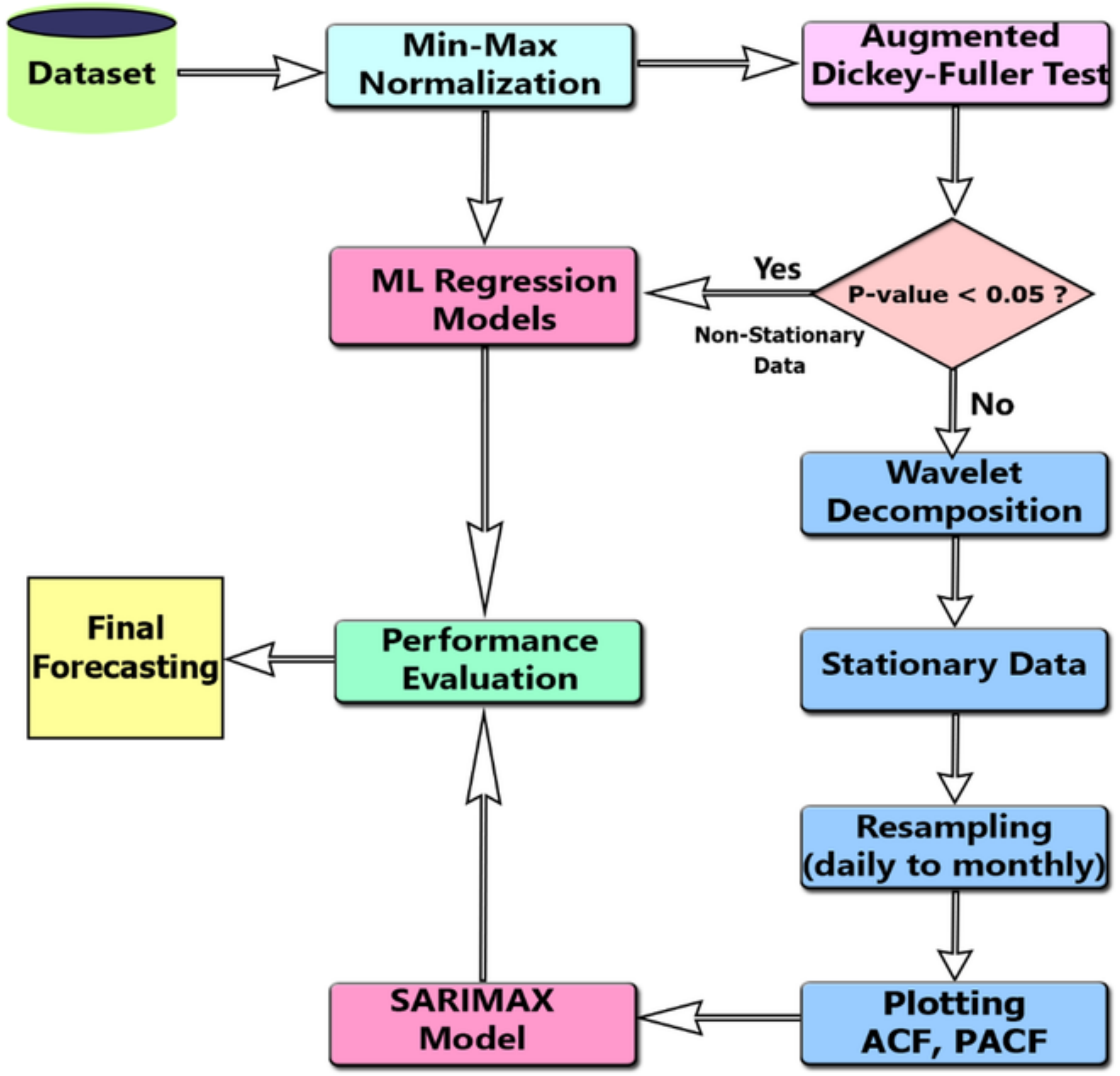
Methods

ML Models

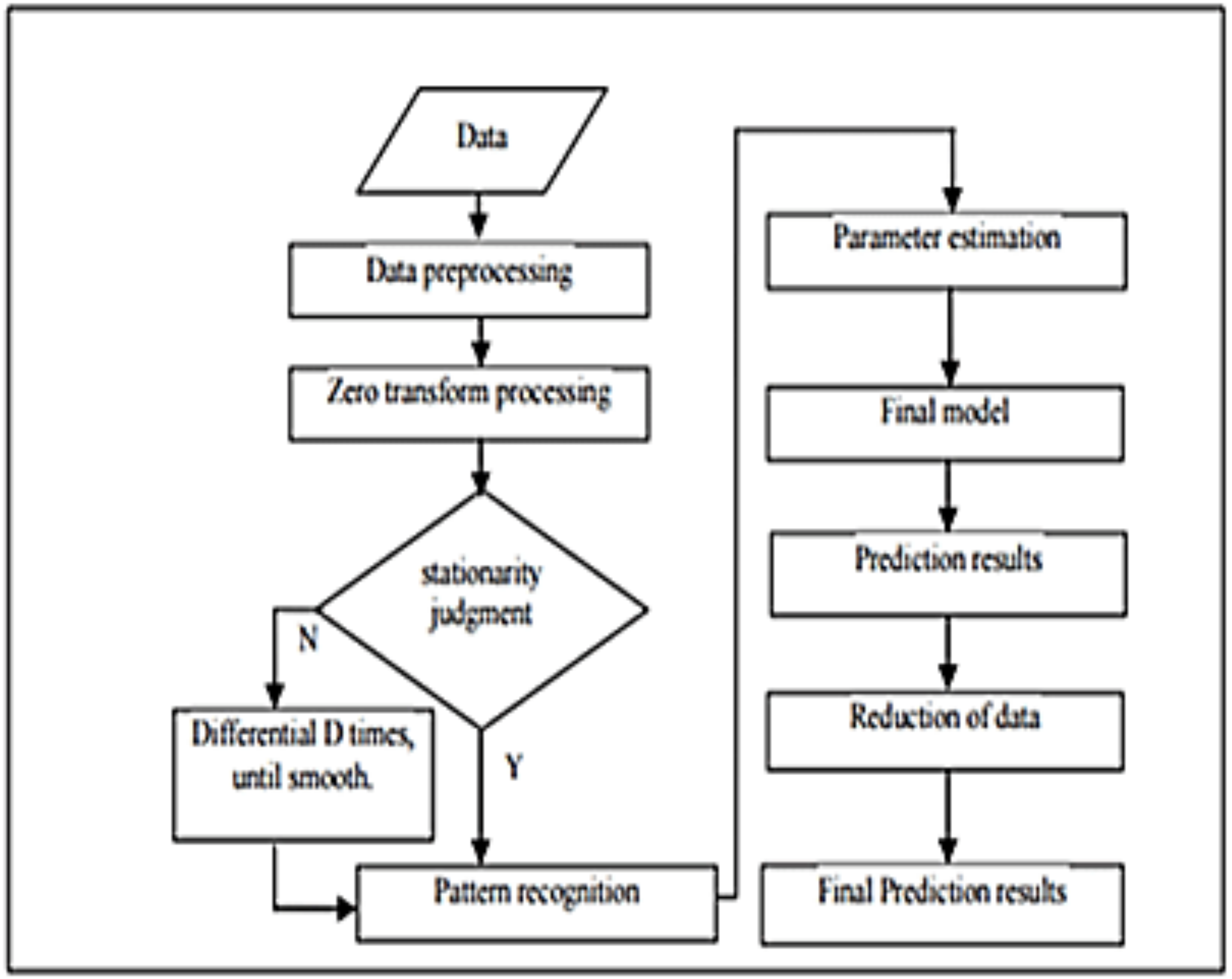
- Selection of a SARIMAX model for forecasting with external regressors.
- Evaluation of multiple model variants with different seasonal orders and regressors.
- Hyper-parameters optimization - tree-structured Parzen estimator for tuning model parameters

Methods

sARIMAx = ARIMA?



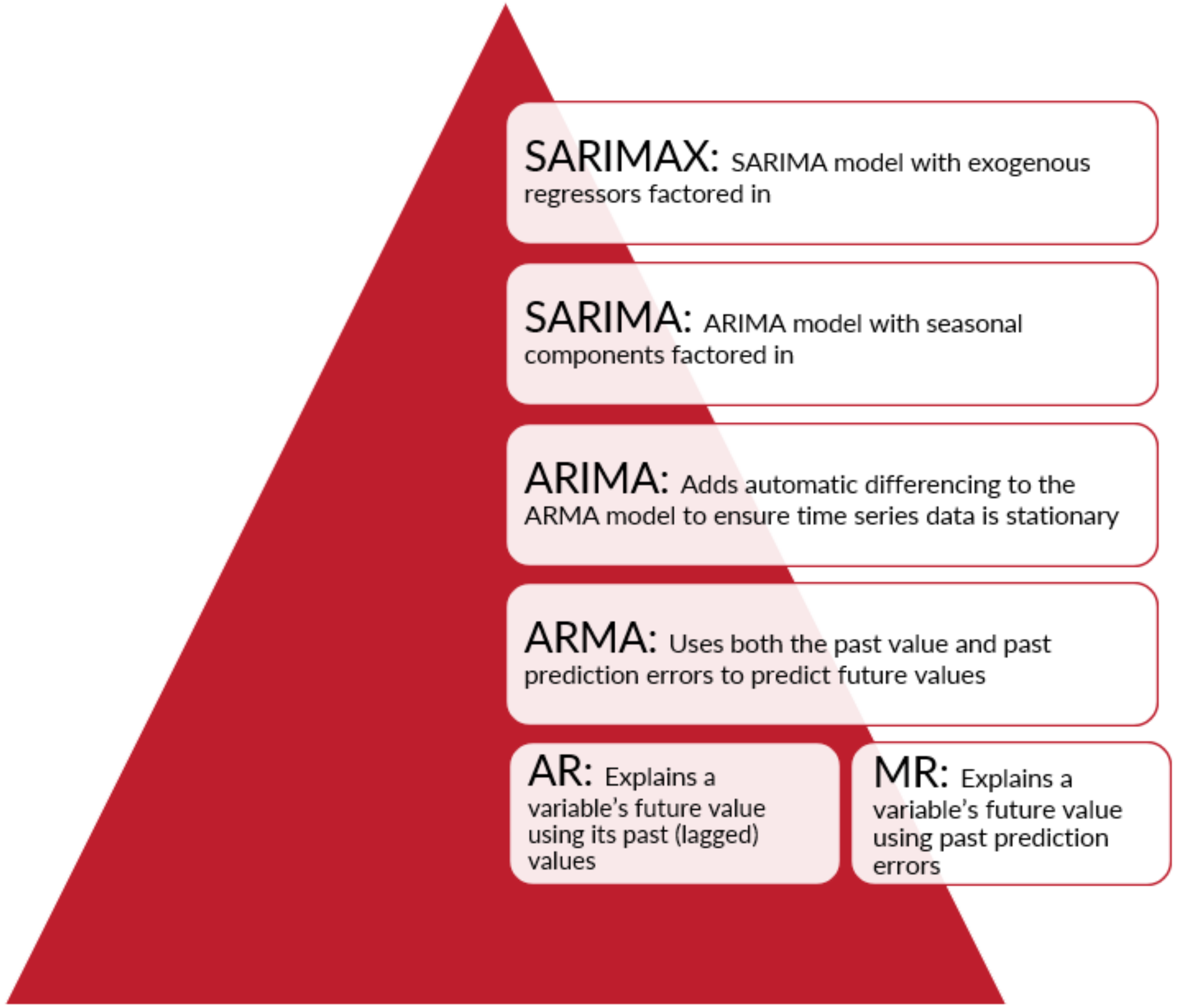
SARIMAX model block-scheme



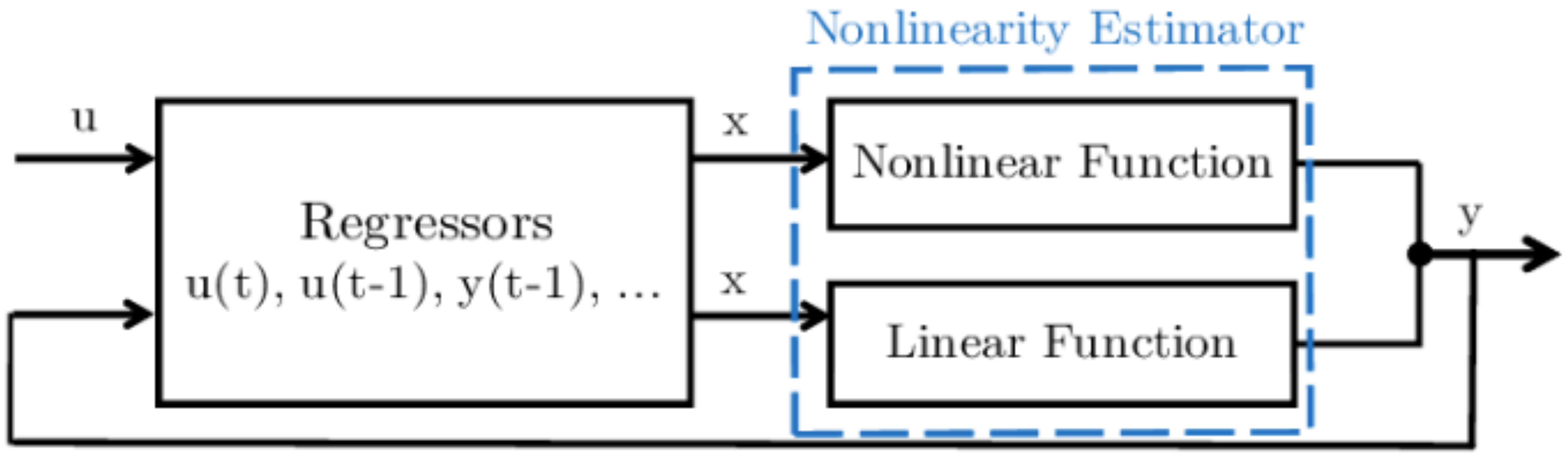
ARIMA model block-scheme

Methods

EXOGENOUS REGRESSORS



ARIMA-based models triangle

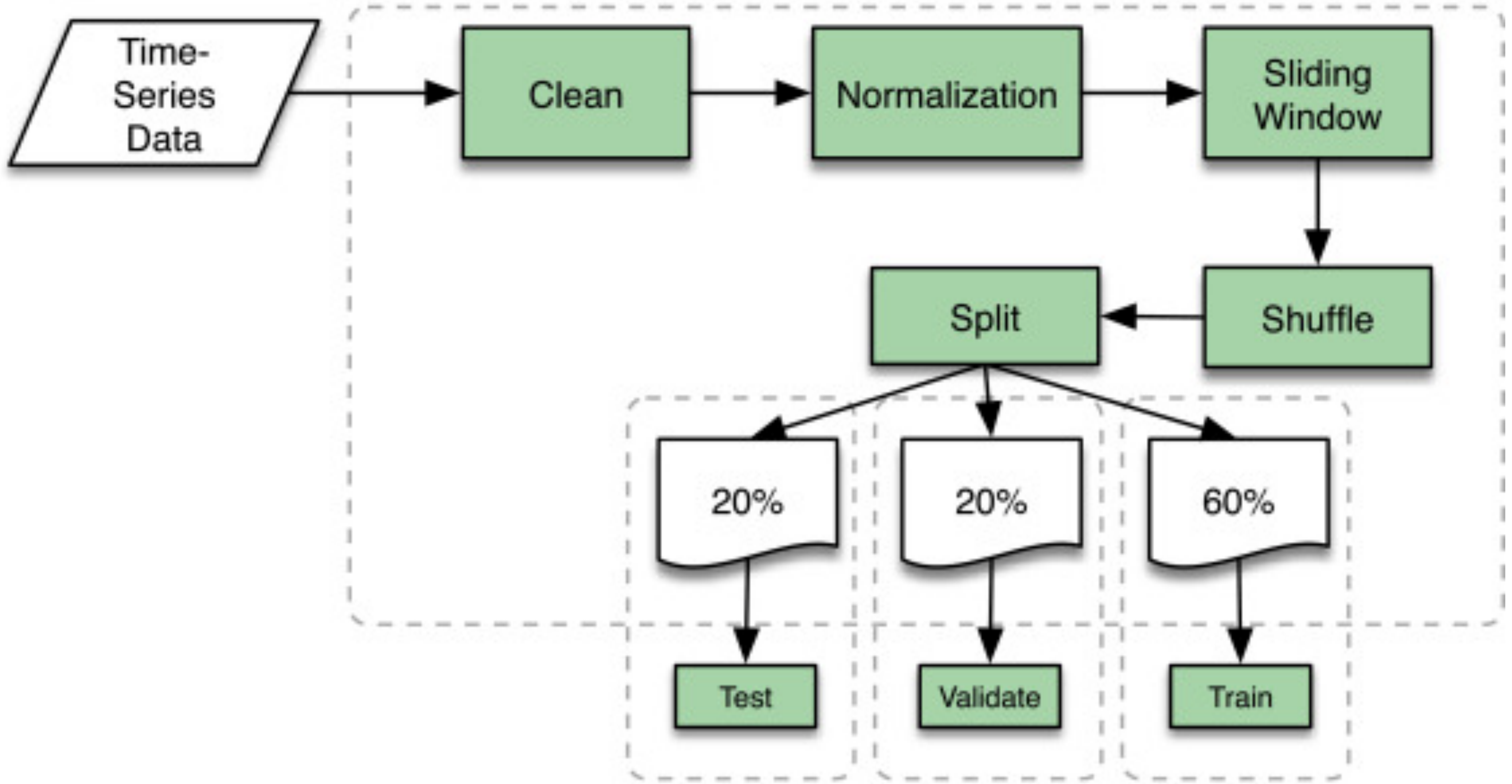


Nonlinear AutoRegressive exogenous model

Experiment

Set-up

- Preparing datasets
- Division of data into training and testing sets (242 + 73 + 50 days).
- Forecasts made 1-4 hours ahead during peak daily hours.
- Assessment of predictive power (to improve forecast accuracy)



TSD splitting

Perfomance metrics

Using a performance metrics to compare
the results of forecasting, by calculating errors

- MAPE
- MAE
- MSE

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Y_i - \hat{Y}_i}{Y_i}\right|$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|y_i - \hat{y}_i\right|$$

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y})^2$$

Experiment

- Testing SARIMAX with regressors for more accurate predictions. (50 days testing period)
- Comparison with other forecasting methods based on MAE, MSE, and MAPE.
- Forecasting time: +4 hours / 03:00 PM + 1 hour
- Evaluation of the width and coverage of prediction intervals.

		80% Prediction interval		95% Prediction interval	
Prediction for	Model	Width	Coverage	Width	Coverage
3:00 PM (1-h-ahead)	Holt-Winters	24.82	79.00	37.96	93.00
	VAR	24.24	79.00	37.07	92.00
	Schweigler et al.	10.58	79.00	16.18	**93.00**
	24-SARIMAX	**10.23**	**83.00**	**15.00**	91.00
4:00 PM (2-h-ahead)	Holt-Winters	25.48	75.00	38.96	92.00
	VAR	24.78	73.00	37.90	91.00
	Schweigler et al.	14.59	67.00	22.31	90.00
	24-SARIMAX	**14.48**	**78.00**	**22.16**	**94.00**
5:00 PM (3-h-ahead)	Holt-Winters	26.01	73.00	39.77	89.00
	VAR	24.98	72.00	38.20	88.00
	Schweigler et al.	**17.27**	64.00	**26.42**	84.00
	24-SARIMAX	17.74	**76.00**	27.13	**91.00**
6:00 PM (4-h-ahead)	Holt-Winters	25.92	76.00	39.64	91.00
	VAR	25.19	76.00	38.52	92.00
	Schweigler et al.	**19.27**	67.00	**29.47**	83.00
	24-SARIMAX	19.58	**78.00**	29.94	**93.00**

24-SARIMAX testing

Results and discussion

- SARIMAX showed the highest accuracy in forecasts 1-4 hours ahead.
- The model reduced error by 60% compared to the rolling average method.
- Advantages of using real-time data to enhance ED operational efficiency.

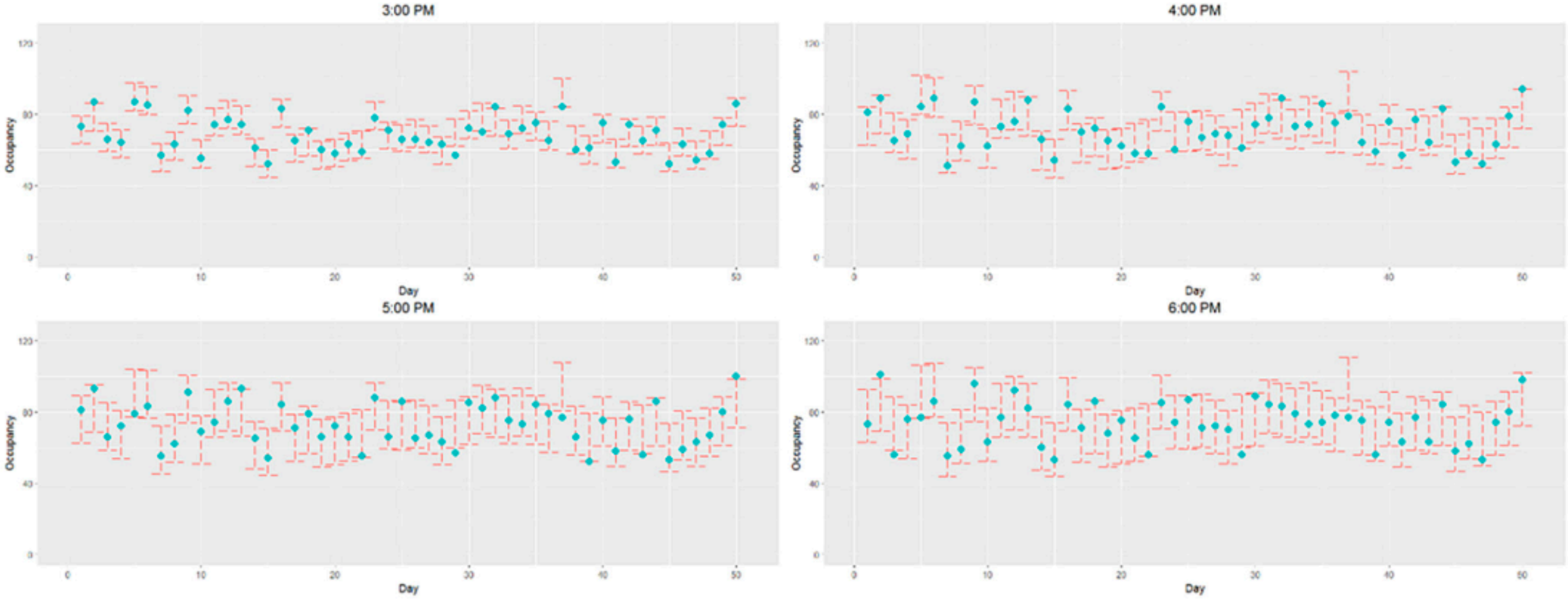
External regressors	MAE	MSE	MAPE
Occupancy	7.13665	74.95466	0.10531
New arrivals over the last 1, 3, and 5 h	8.80926	114.16462	0.13139
Occupancy and ESI	6.58473	67.41719	0.09693
Occupancy, ESI, and boarding total	6.38104	64.47098	0.09443

Comparison of SARIMAX with different regressors

		Performance metrics		
Prediction for	Model	MSE	MAE	MAPE
3:00 PM (1-h-ahead)	Rolling Average	123.136	8.702	0.145
	Holt-Winters	106.704	7.694	0.125
	VAR	100.465	7.712	0.127
	Schweigler et al.	21.600	3.668	0.058
	Whitt et al.	31.057	4.484	0.070
	24-SARIMAX	**16.196**	**3.158**	**0.050**
4:00 PM (2-h-ahead)	Rolling Average	155.597	9.736	0.159
	Holt-Winters	140.814	9.091	0.147
	VAR	127.164	8.490	0.137
	Schweigler et al.	50.554	5.803	0.090
	Whitt et al.	66.471	6.437	0.100
	24-SARIMAX	**36.195**	**4.875**	**0.075**
5:00 PM (3-h-ahead)	Rolling Average	170.959	10.083	0.160
	Holt-Winters	158.715	9.859	0.153
	VAR	142.490	9.369	0.146
	Schweigler et al.	80.894	7.428	0.111
	Whitt et al.	101.496	7.886	0.120
	24-SARIMAX	**58.196**	**6.172**	**0.092**
6:00 PM (4-h-ahead)	Rolling Average	169.254	9.821	0.153
	Holt-Winters	153.722	9.432	0.146
	VAR	140.310	9.187	0.141
	Schweigler et al.	92.178	7.797	0.117
	Whitt et al.	107.997	8.036	0.122
	24-SARIMAX	**64.471**	**6.381**	**0.094**

Perfomance comparison of SARIMAX with existing models

Results and discussion



95% prediction intervals of the first 50 days in the test set provided by our model 24-SARIMAX.

Limitations

- Use of data from only one year. (May not capture long-term trends).
- Only one medical center.
- Limited number of variables.
- SARIMAX provides accurate forecasts only for a short period.

Conclusion

- The 24-SARIMAX model enables more accurate ED occupancy forecasting.
- Use of real-time available data to enhance predictive accuracy
- Model simplicity makes it accessible for integration into ED systems.
- The results of SARIMAX are ideal for short-term forecasting,
  as this model provides some of the most accurate outcomes.

Thank you for listening!

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