

APPENDIX A DATA

The data covers a period of one and a half years, starting from 01.01.2022 until 30.06.2023. In addition to the data obtained from the Augsburg University Hospital, we use exogenous variables. These include Bavarian school holidays and public holidays together with the closest distance to each holiday, i.e. either the distance to the previous or the next holiday. We further add calendar features which we encode by sine and cosine transformation.

We also include the region's influenza incidence [1], i.e. the weekly number of confirmed cases of influenza per 100.000 persons in Bavaria. Furthermore, we include the weekly estimated incidence of Influenza-like Illness (ILI) and Acute Respiratory Illness (ARI) [2] in South Germany. We only consider the overall incidence and do not differ between age groups.

The complete set of variables is provided in Table I below. In Table II, descriptive statistics of the dataset are reported. Furthermore, Tables III, IV and V show the subset statistics when splitting the dataset according to the three main shifts, consisting of early (06:00 am to 01:59 pm), late (02:00 pm to 09:59 pm), and night shift (10:00 pm to 5:59 am).

TABLE I
EXOGENOUS VARIABLES FOR MODEL TRAINING ALONG WITH THEIR SOURCE, TYPE, AND FREQUENCY. *H* = HISTORICAL COVARIATE, *F* = FUTURE COVARIATE.

Exogenous Variable	Source	Type	Frequency
Nursing staff capacity of ward B-D	[3]	<i>H</i>	hourly
Unplanned absences of ward A-D	[3]	<i>H</i>	hourly
Influenza incidence	[1]	<i>H</i>	weekly
Influenza-like Illness (ILI) incidence	[2]	<i>H</i>	weekly
Acute Respiratory Illness (ARI) incidence	[2]	<i>H</i>	weekly
Planned absences of ward A-D	[3]	<i>F</i>	hourly
Bavarian school holidays	[4]	<i>F</i>	daily
Bavarian public holidays	[4]	<i>F</i>	daily
Sine transformed hour of day	-	<i>F</i>	hourly
Cosine transformed hour of day	-	<i>F</i>	hourly
Sine transformed day of week	-	<i>F</i>	daily
Cosine transformed day of week	-	<i>F</i>	daily
Sine transformed day of year	-	<i>F</i>	daily
Cosine transformed day of year	-	<i>F</i>	daily
Sine transformed day of month	-	<i>F</i>	daily
Cosine transformed day of month	-	<i>F</i>	daily
Sine transformed month of year	-	<i>F</i>	monthly
Cosine transformed month of year	-	<i>F</i>	monthly
Distance to Corpus Christi	[4]	<i>F</i>	daily
Distance to Assumption Day	[4]	<i>F</i>	daily
Distance to German Unity Day	[4]	<i>F</i>	daily
Distance to All Saints Day	[4]	<i>F</i>	daily
Distance to Christmas Day	[4]	<i>F</i>	daily
Distance to Boxing Day	[4]	<i>F</i>	daily
Distance to New Year's Day	[4]	<i>F</i>	daily
Distance to Epiphany	[4]	<i>F</i>	daily
Distance to Good Friday	[4]	<i>F</i>	daily
Distance to Easter Monday	[4]	<i>F</i>	daily
Distance to Labour Day	[4]	<i>F</i>	daily
Distance to Ascension Day	[4]	<i>F</i>	daily
Distance to Day of Prayer and Repentance	[4]	<i>F</i>	daily
Distance to Whit Monday	[4]	<i>F</i>	daily
Distance to Whitsun holidays	[4]	<i>F</i>	daily
Distance to summer holidays	[4]	<i>F</i>	daily
Distance to autumn holidays	[4]	<i>F</i>	daily
Distance to Christmas holidays	[4]	<i>F</i>	daily
Distance to spring holidays	[4]	<i>F</i>	daily
Distance to Easter holidays	[4]	<i>F</i>	daily

TABLE II
STATISTICS OF THE DATASET.

Exogenous Variable	mean	std	min	max
Nursing staff capacity of ward A	11.2	6.5	3.0	35.0
Planned absences of ward A	51.0	12.7	24.0	75.0
Unplanned absences of ward A	10.4	3.1	2.0	26.0
Nursing staff capacity of ward B	10.4	6.0	2.0	34.0
Planned absences of ward B	50.2	8.6	30.0	70.0
Unplanned absences of ward B	9.1	2.9	3.0	25.0
Nursing staff capacity of ward C	7.9	4.9	1.0	29.0
Planned absences of ward C	32.8	5.8	21.0	48.0
Unplanned absences of ward C	4.3	2.4	0.0	15.0
Nursing staff capacity of ward D	11.5	7.2	3.0	36.0
Planned absences of ward D	34.6	6.9	18.0	49.0
Unplanned absences of ward D	5.5	2.4	0.0	20.0
Influenza incidence	6.5	15.7	0.1	81.1
Influenza-like Illness (ILI) incidence	1645.4	756.4	373.0	3982.0
Acute Respiratory Illness (ARE) incidence	5908.7	2146.3	2085.0	10761.0

TABLE III
STATISTICS OF THE EARLY SHIFT.

Exogenous Variable	mean	std	min	max
Nursing staff capacity of ward A	17.1	5.2	7.0	35.0
Planned absences of ward A	51.0	12.8	24.0	75.0
Unplanned absences of ward A	10.5	3.0	3.0	22.0
Nursing staff capacity of ward B	14.8	4.7	6.0	34.0
Planned absences of ward B	50.2	8.6	30.0	70.0
Unplanned absences of ward B	9.1	2.9	3.0	21.0
Nursing staff capacity of ward C	11.9	4.4	3.0	29.0
Planned absences of ward C	32.8	5.8	21.0	48.0
Unplanned absences of ward C	4.4	2.3	0.0	13.0
Nursing staff capacity of ward D	17.3	6.2	6.0	36.0
Planned absences of ward D	34.6	6.9	18.0	49.0
Unplanned absences of ward D	5.5	2.5	1.0	20.0

TABLE IV
STATISTICS OF THE LATE SHIFT.

Exogenous Variable	mean	std	min	max
Nursing staff capacity of ward A	10.5	4.9	4.0	34.0
Planned absences of ward A	51.0	12.7	24.0	75.0
Unplanned absences of ward A	10.3	2.8	3.0	19.0
Nursing staff capacity of ward B	11.7	4.8	5.0	32.0
Planned absences of ward B	50.2	8.6	30.0	70.0
Unplanned absences of ward B	9.0	2.8	3.0	21.0
Nursing staff capacity of ward C	8.0	3.9	2.0	29.0
Planned absences of ward C	32.8	5.8	21.0	48.0
Unplanned absences of ward C	4.3	2.2	0.0	12.0
Nursing staff capacity of ward D	11.9	5.6	6.0	35.0
Planned absences of ward D	34.6	6.9	18.0	49.0
Unplanned absences of ward D	5.4	2.3	1.0	17.0

TABLE V
STATISTICS OF THE NIGHT SHIFT.

Exogenous Variable	mean	std	min	max
Nursing staff capacity of ward A	6.0	3.7	3.0	21.0
Planned absences of ward A	51.0	12.8	24.0	75.0
Unplanned absences of ward A	10.4	3.5	2.0	26.0
Nursing staff capacity of ward B	4.8	3.1	2.0	19.0
Planned absences of ward B	50.2	8.6	30.0	70.0
Unplanned absences of ward B	9.1	3.0	3.0	25.0
Nursing staff capacity of ward C	3.7	2.2	1.0	15.0
Planned absences of ward C	32.8	5.8	21.0	48.0
Unplanned absences of ward C	4.3	2.6	0.0	15.0
Nursing staff capacity of ward D	5.3	3.4	3.0	21.0
Planned absences of ward D	34.6	6.9	18.0	49.0
Unplanned absences of ward D	5.5	2.5	0.0	18.0

APPENDIX B

HYPERPARAMETER OPTIMIZATION

The results of the hyperparameter optimization along with their search spaces are provided below for each model.

TABLE VI
HYPERPARAMETER OPTIMIZATION TSMIXER

Hyperparameter	Search space	Selected value				
		U	H	HF	<i>only [3]</i>	<i>without[3]</i>
Learning rate	{0.00001, ..., 0.1}	0.001	0.001	0.001	0.001	0.001
Look-back	{24, 96, 336, 720}	720	720	720	720	720
Dropout	{0.1, ..., 0.9}	0.1	0.2	0.1	0.2	0.1
Nr. of mixing layers	{1, 2, 3, 4}	2	3	2	3	2
Hidden size of first feed-forward layer	{64, 128, 256, 512}	256	256	256	256	256
Hidden state size	{64, 128, 256, 512}	256	256	256	256	256
Nr. of epochs	-	30	30	30	30	30
batch size	-	32	32	32	32	32
early stopping patience	-	10	10	10	10	10
Nr. of trials	-	30	30	30	30	30

TABLE VII
HYPERPARAMETER OPTIMIZATION TiDE

Hyperparameter	Search space	Selected value		
		U	H	HF
Learning rate	{0.00001, ..., 0.1}	0.0001	0.0001	0.0001
Look-back	{24, 96, 336, 720}	720	336	96
Dropout	{0.1, ..., 0.9}	0.2	0.3	0.4
Nr. of encoder layers	{1, 2, 3}	2	3	1
Nr. of decoder layers	{1, 2, 3}	2	2	2
Hidden size	{256, 512, 1024}	1024	1024	512
Temporal decoder hidden size	{32, 64, 128}	32	128	64
Decoder output dimension	{4, 8, 16, 32}	32	4	4
Nr. of epochs	-	30	30	30
batch size	-	32	32	32
early stopping patience	-	10	10	10
Nr. of trials	-	30	30	30

TABLE VIII
HYPERPARAMETER OPTIMIZATION PATCHTST

Hyperparameter	Search space	Selected value
Learning rate	{0.00001, ..., 0.1}	0.01
Look-back	{24, 96, 336, 720}	720
Dropout	{0.1, ..., 0.9}	0.5
Patch length	{8, 12, 16}	16
Stride	-	8
Nr. of attention heads	-	4
Nr. of encoder layers	-	3
Hidden size in residual blocks	-	16
Hidden size of linear layer	-	128
Nr. of epochs	-	30
batch size	-	32
early stopping patience	-	10
Nr. of trials	-	30

TABLE IX
HYPERPARAMETER OPTIMIZATION LIGHTGBM

Hyperparameter	Search space	Selected value		
		U	H	HF
Learning rate	$\{0.00001, \dots, 0.1\}$	0.1	0.1	0.1
Lags	$\{[-24], [-168, -24], [-336, -168, -24]\}$	[-24]	[-24]	[-168, -24]
Lags Past Covariates	$\{[-24], [-168, -24], [-336, -168, -24]\}$	-	[-336, -168, -24]	[-24]
Lags Future Covariates	$\{[24], [24, 168], [24, 168, 336]\}$	-	-	[24, 168]
Nr. of leaves	$\{15, 20, \dots, 45, 50\}$	25	30	25
Nr. of estimators	$\{50, 60, \dots, 90, 100\}$	80	70	70
minimum child samples	$\{10, 20, 30, 40\}$	20	10	30

APPENDIX C FORECASTS

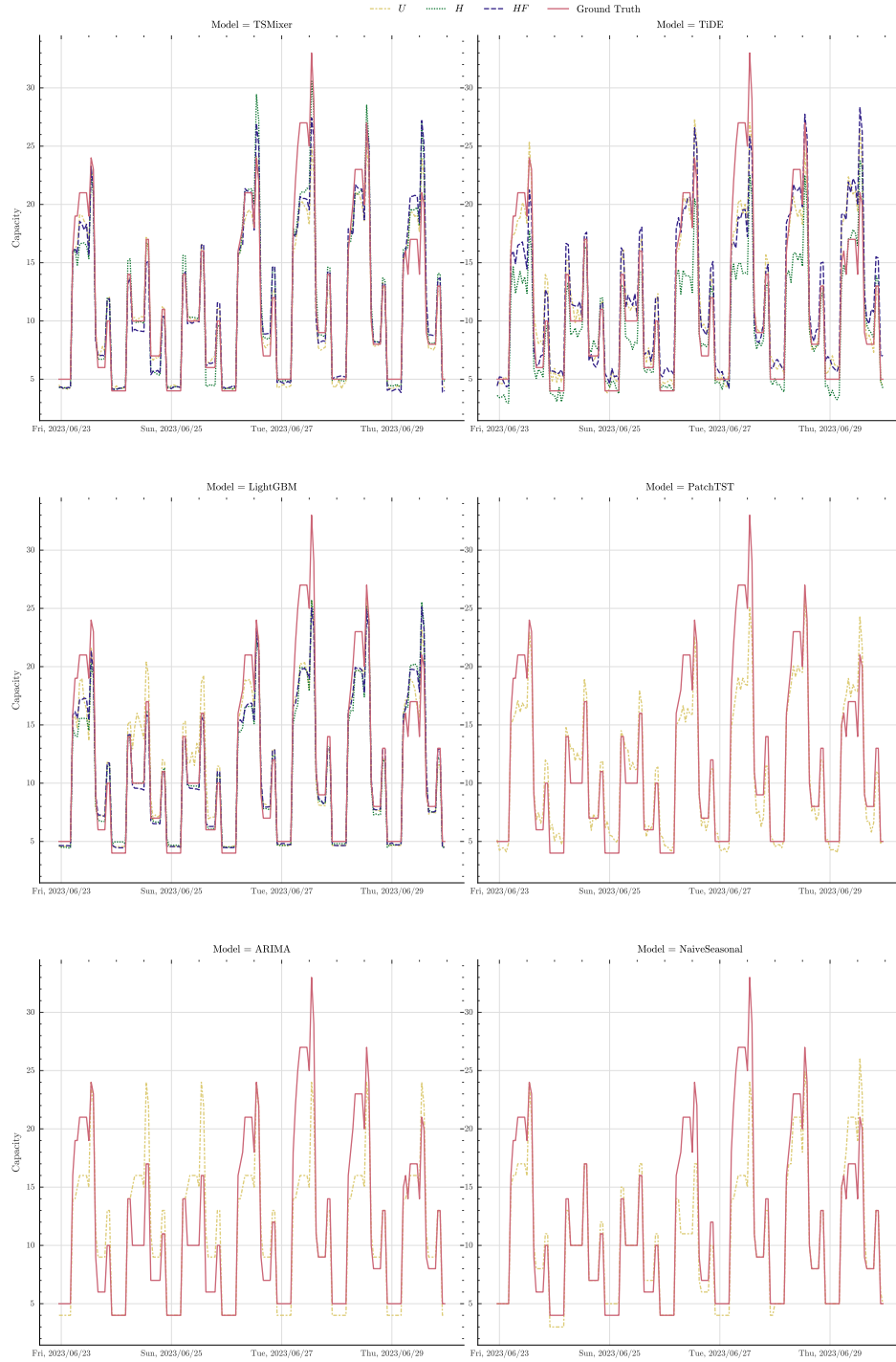


Fig. 1. Forecast of the last seven days of the test set for each model and applicable feature subset.

APPENDIX D

CODE AVAILABILITY

The code of the experiments presented in this paper is currently under refinement to ensure it meets the necessary standards of code quality and reproducibility. We are committed to the principles of open science and plan to make the code publicly available in the near future.

REFERENCES

- [1] Robert Koch-Institut, “Laborbestätigte Influenzafälle in Deutschland,” Apr. 2024. [Online]. Available: https://robert-koch-institut.github.io/Influenzafaelle_in_Deutschland/
- [2] U. Buchholz, S. Buda, A.-S. Lehfeld, A. Loenenbach, K. Prahm, U. Preuß, and W. Haas, “Grippeweb - daten des wochenberichts,” Apr. 2024. [Online]. Available: <https://doi.org/10.5281/zenodo.10925141>
- [3] E. Schiller, S. Mueller, K. Ebertsch, and J.-P. Steghoefer, “University Hospital Augsburg nursing staff capacity,” May 2024. [Online]. Available: <https://doi.org/10.5281/zenodo.11104488>
- [4] STÜBER SYSTEMS GmbH, “Open Holidays API,” <https://www.openholidaysapi.org/en/>, accessed: 2024-04-25.