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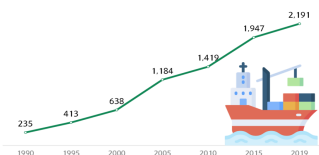
&

가

가

- 2022

가



Multi horizon

- 1 () :

- 3~5 () :

(3~5) { , (2014), (2019)}

- Encoder-Decoder

2.

&

가

- Monte Carlo Dropout

-

가

3.

- &

가

Scenario Forecasting 가

ARIMA VAR - VEC (2020)	ARIMA VAR, VEC	.GDP,		ARIMA VECM
(2019)	ARIMA LSTM, GRU	&		LSTM & GRU가 ARIMA 가
(2021)	ARIMA VAR, LSTM, GRU	가		RMSE 가
Prophet (2022)	ARIMA, LSTM, Prophet			, ARIMA Prophet LSTM

-
-
-

1. (20)
2. (16)
3. Encoder-Decoder & Attention (8)
4. (8)

-
-
-

One-Step Ahead Prediction

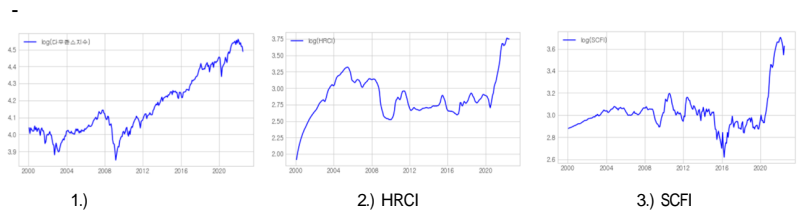
&

2000.01 ~ 2022.06		
	(TEU) *	가 /
	BDI()	Investing.com
	SCFI() *	En.macromicro.me
	HRCI(Howe Robinson) *	가
		Investing.com
	/	
	가	
		가 /

&

1.
 - 2000 TEU : [2001.01 ~ 2001.12 / TEU (1.23)] × [2000.01 ~ 2000.12 TEU]
 - HRCI : 2002.01 ~ 2022.06 가 --> 2000.01 ~ 2001.12 ARIMA
 - SCFI : [SCFI (2009.10.16 ~ 2022.06.24) + CCFI (2002.01.11 ~ 2009.10.09)]
--> 2000.01 ~ 2001.12 ARIMA

2.



&

3. Multi Horizon (8)

- 1 [17.07 ~ 18.06] , [18.07 ~ 19.06] , [19.07 ~ 20.06] , [20.07 ~ 21.06] , [21.07 ~ 22.06] --> 5
- 3 [2017.07 ~ 2020.06] , [2019.07 ~ 2022.06] --> 2
- 5 [2017.07 ~ 2020.06] --> 1

4. Sliding Window & Min-Max Scaling

Sequence Length	
1년 단위 예측	Input Sequence = 18, Prediction Length = 12
3년 단위 예측	Input Sequence = 18, Prediction Length = 36
5년 예측	Input Sequence = 20, Prediction Length = 60

- Train [2000.01 ~ 2017.06] & Test [2017.07 ~ 2022.06] --> Min-Max Scaler
- (B,T,D) 3 Sequence & 8 Multi Horizon

1. Encoder-Decoder Layer

- LSTM, CNN-LSTM, TCN(Temporal Convolutional Network), LSTM-Attention

2. Prediction Uncertainty

- Monte Carlo Dropout

3. Probability Distribution Similarity

- KL-Divergence, Negative Log-Likelihood

4. Probabilistic Forecast Measure

- CRPS(Continuous Ranked Probability Score), Coverage, Sharpness

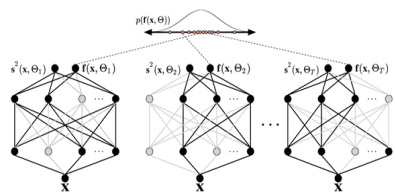
5. Priority Prediction Value Set

- Mean MCD Pred, TEU Seasonality, Euclidean Distance, JS-Distance, DTW

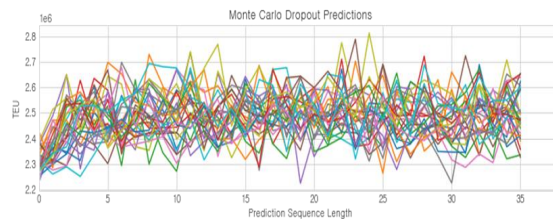
Monte Carlo Dropout

- Epistemic Uncertainty []
- BNN, Gaussian Process, Variational Inference
- Dropout
- MC-Dropout

Uncertainty Quantification



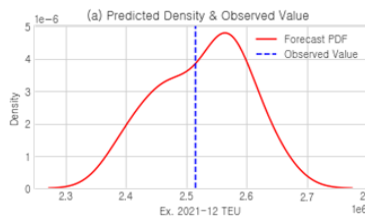
MC-Dropout =0.8,



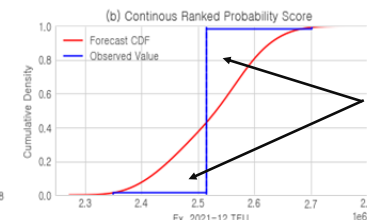
N=30

CRPS(Continuous Ranked Probability Score)

- Multi Horizon N=30



(a) Probability Density Function



(b) Cumulative Density Function

$$crps_{F,y} = \int_{-\infty}^{\infty} [F(t) - I(t \geq y)]^2 dt$$

- 가

$$CRPS = \frac{1}{T} \sum_{i=1}^T crps(F_i, y_i)$$

Coverage(Prediction Interval Coverage Probability)

(ex. 95% Prediction Interval)

$$Coverage = \frac{1}{T} \sum_{i=1}^T \{ (Y_i > Lower PI_i) \cap (Y_i < Upper PI_i) \}$$

Sharpness(Mean Prediction Interval Width)

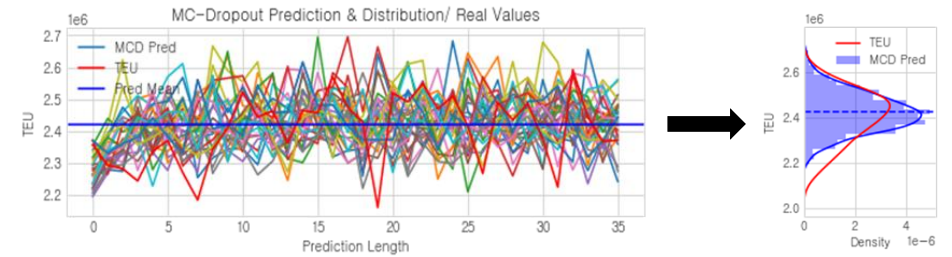
(ex. 95% Prediction Interval)

$$Sharpness = \frac{1}{T} \sum_{i=1}^T (Upper PI_i - Lower PI_i)$$

가

CRPS

1. MLE MC-Dropout



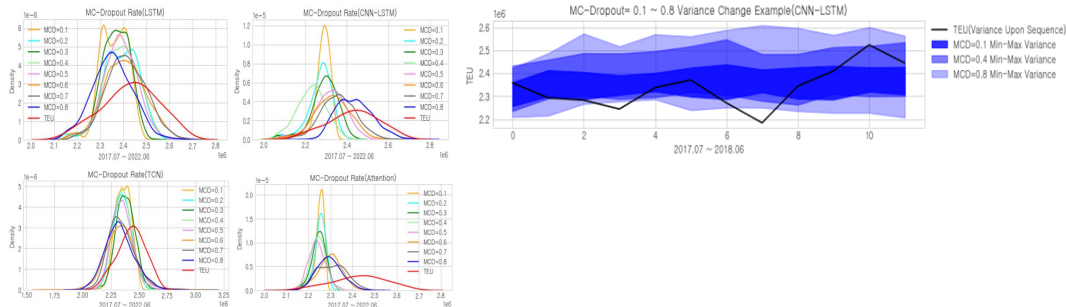
가

- MC-Dropout 0.1~0.8
- MLE 가 MC-Dropout
- & Horizon N=30

• , MC-Dropout 가

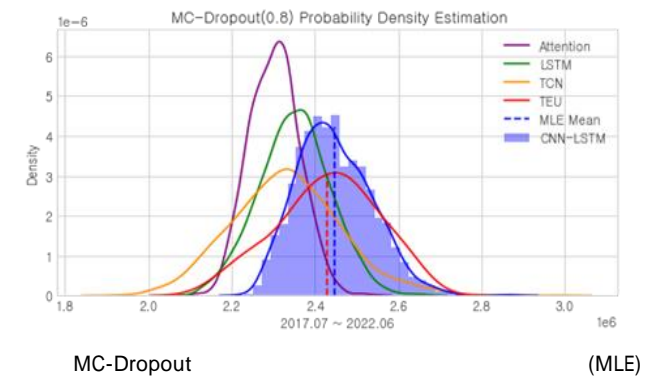
• MC-Dropout=0.8

MC-Dropout



• CNN-LSTM Layer

가



MC-Dropout

(MLE)

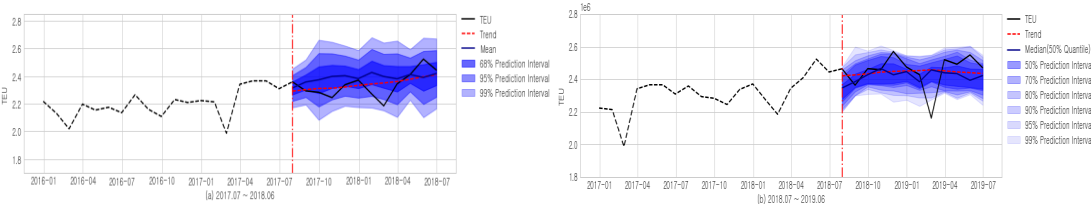
- Monte Carlo Dropout=0.8 & N=30
 - MC-Dropout=0.8 & N=30
 - Negative Log-Likelihood, CNN-LSTM 가 KL-Divergence,
 - CNN-LSTM Encoder-Decoder(MCD=0.8) 가

KL-Divergence				
MC-Dropout=0.8 Encoder-Decoder				
예측기간	LSTM	CNN-LSTM	TCN	Attention
2017.07~2018.06	382774	654165	399003	536973
2018.07~2019.06	603162	326301	993505	997807
2019.07~2020.06	389196	551593	618384	281291
2020.07~2021.06	977680	551098	1469896	930074
2021.07~2022.06	680140	383917	1083607	760118
2017.07~2020.06	1354819	1045959	2763750	4458365
2019.07~2022.06	1142756	1387508	4641674	1578009
2017.07~2022.06	4445308	1529650	5457136	72654505
평균	1246979.375	803773.875	2178369.375	2101005.25

Negative Log-Likelihood				
MC-Dropout=0.8 Encoder-Decoder				
예측기간	LSTM	CNN-LSTM	TCN	Attention
2017.07~2018.06	4543	4640	4607	4513
2018.07~2019.06	4648	4613	4726	4640
2019.07~2020.06	4616	4644	4642	4513
2020.07~2021.06	4725	4682	4819	4660
2021.07~2022.06	4676	4656	4757	4614
2017.07~2020.06	13721	13862	14317	14379
2019.07~2022.06	13875	13995	14771	13783
2017.07~2022.06	23549	23216	24417	23952
평균	9294.75	9288.5	9632	9381.75

2. Uncertainty Quantification

- 3-Sigma Based(Gaussian) Prediction Interval [
- ± 2 95%
- ± 1 68%
• Quantile Based Prediction Interval [
- [0.025,0.975] 95%
- [0.15,0.85] 70%



- 2. CRPS CNN-LSTM 가 Coverage Sharpness 가

Monte Carlo Dropout Prediction				
평가 지표	Encoder-Decoder			LSTM
	LSTM	CNN-LSTM	TCN	Attention
평균값 MAPE	4.183	3.823	5.36	5.03
평균값 RMSE	120882	113658	153969	1444462
중앙값 MAPE	4.267	3.813	5.63	5.067
중앙값 RMSE	125704	113605	161813	145607
2σ 95% PI Coverage	0.651	0.842	0.8461	0.3837
2σ 95% PI Sharpness	270785	306066.90	4850404.51	110372.87
[0.025,0.975] 95% PI Coverage	0.603	0.749	0.821	0.359
[0.025,0.975] 95% PI Sharpness	236327.4	266479.06	428196.63	151226.09
CRPS	78728.533	66868.954	97022.659	104242.804

- 2. CRPS CNN-LSTM 가

Monte Carlo Dropout Prediction				
평가 지표	Encoder-Decoder			LSTM
	LSTM	CNN-LSTM	TCN	Attention
평균값 MAPE	2.3487	1.3756	4.729	3.9737
평균값 RMSE	64725.83	40801.33	121286.39	101930.74
중앙값 MAPE	2.4612	1.467	5.126	4.069
중앙값 RMSE	65475.287	43459.0567	131797.97	101984.533
1σ 68% PI Coverage	0.5397	0.9159	0.5096	0.17123
1σ 68% PI Sharpness	135390.587	153033.327	242520.276	69885.6617
[0.15,0.85] 70% PI Coverage	0.5994	0.9151	0.4454	0.12248
[0.15,0.85] 70% PI Sharpness	130906.848	150622.45	211314.88	63988.7323
CRPS	78728.533	66868.954	97022.659	104242.804

3.

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- Coverage Sharpness
- CRPS
- CRPS가

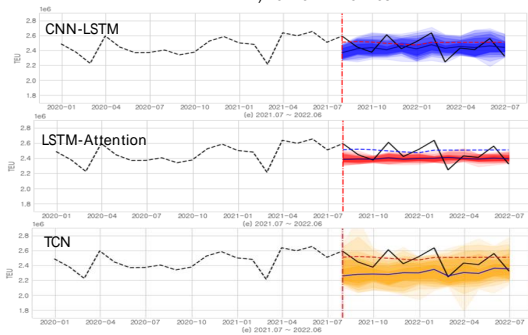
가

가

가

가

Ex.) 2021.07 ~ 2022.06



CRPS: 74383.60

Coverage: 0.833

Sharpness: 312675

Mean MAPE: 4.07

Median MAPE : 4.18

CRPS: 92140.32

Coverage: 0.416

Sharpness: 135853.53

Mean MAPE: 4.31

Median MAPE : 4.38

CRPS: 119384.57

Coverage: 0.75

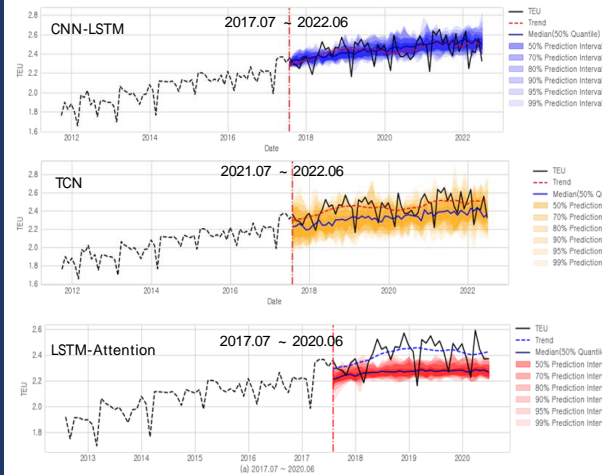
Sharpness: 49714.68

Mean MAPE: 6.45

Median MAPE : 6.67

3.

2



CRPS: 65871.88

Coverage: 0.683

Sharpness: 222531.8

Mean MAPE: 3.71

Median MAPE : 3.66

CRPS: 90153.78

Coverage: 0.833

Sharpness: 427263.54

Mean MAPE: 5.03

Median MAPE : 5.22

CRPS: 83248.53

Coverage: 0.25

Sharpness: 146162.84

Mean MAPE: 5.91

Median MAPE : 6.07

3.

CRPS가 CNN-LSTM
가

가 가

CRPS

- CRPS, KL-Divergence, Negative Log-Likelihood

4. 가

- MC-Dropout 100,200,500
- CNN-LSTM Encoder-Decoder

CRPS

30

- MCD=30 [CRPS = 66868.954, MCD=100 [CRPS=66104.8], MCD=200 [CRPS=67174], MCD=500 [CRPS = 66878.46]

CRPS = 92113.05

- 10 가

MC-Dropout

CNN-LSTM Encoder-Decoder

4. 가

Continuous Ranked Probability Score				
예측 기간	MC-Dropout 출력 개수			
	30	100	200	500
1Y	67890.706	67089.4	69315	68405.4
3Y	66844.275	64944	65913	65660
5Y	65871.88	66281	66294	66570
전체 평균	66868.954	66104.8	67174	66878.46

Monte Carlo Dropout Prediction		
평가 지표	CNN LSTM Encoder-Decoder	
	Univariate	Multivariate
평균값 MAPE	4.79	3.823
평균값 RMSE	137746	113658
중앙값 MAPE	4.84	3.813
중앙값 RMSE	138532	113605
2σ 95% PI Coverage	0.582	0.842
2σ 95% PI Sharpness	219508.9	306066.90
[0.025,0.975] 95% PI Coverage	0.568	0.749
[0.025,0.975] 95% PI Sharpness	226618.19	266479.06
CRPS	92113.05	66868.954

4. 가 (Multi Horizon ARIMA, VECM, Prophet One-Step Ahead DL)

5
Decoder

, MC-Dropout CNN-LSTM Encoder-

성능 비교		
방법론	MAPE	RMSE
LSTM	4.31	128746
GRU	4.14	125469
CNN-LSTM	3.75	118493
TCN	4.93	145384
VECM	4.28	125623
ARIMA	5.78	181322
Prophet	4.06	181322
MCD-CNN-LSTM Encoder-Decoder (Mean)	3.71	111060
MCD-CNN-LSTM Encoder-Decoder (Median)	3.66	109749

5. (Scenario Forecasting)

- , CNN-LSTM (MAPE 1.4%)

- ()

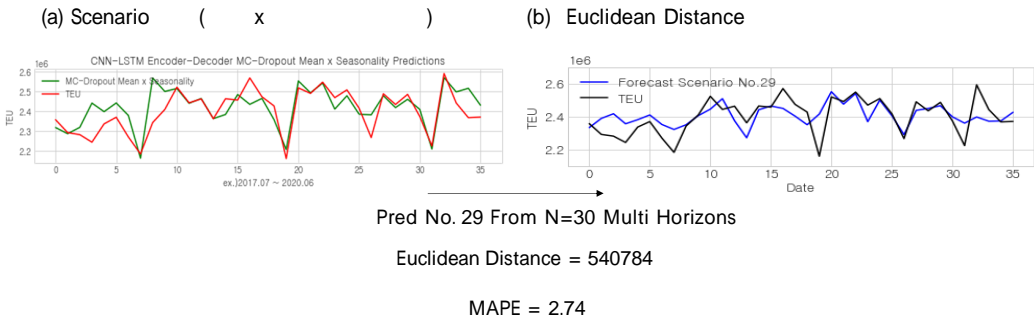
- 30 JS(Jensen Shannon) Distance, Euclidean Distance, DTW(Dynamic Time Warping)

3 5

MC-Dropout 가 5

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5. (Scenario Forecasting)



5.

2019.07 ~ 2022.06					
MC-Dropout Best Predictions					
Pred No.	17	6	25	4	21
MAPE	3.91	4.00	4.02	4.13	4.34
JS-Distance					
Distance	0.012044	0.013709	0.014641	0.014931	0.015454
Pred No.	21	7	1	17	6
MAPE	4.34	4.94	4.84	3.91	4.00
Euclidean Distance					
Distance	567127	612222	615392	649793	679009
Pred No.	21	1	7	4	25
MAPE	4.34	4.84	4.94	4.13	4.02
Dynamic Time Warping					
Distance	401866	423161	423403	431783	435740
Pred No.	18	13	21	25	12
MAPE	6.77	5.05	4.34	4.02	4.74

x MC-Dropout
가 5

1

MC-Dropout 가 5 Scenario /

1.

Monte-Carlo Dropout Multi Horizon Encoder-Decoder
CRPS(Continuous Ranked Probability Score)가 가 --> CNN-LSTM
가 (MC-Dropout &)
Scenario

2.

2000 1
100%

가 &

DeepAR, NHITS

가

End