LSTM R/Quarto Pipeline

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Load time series

```
data <- read.csv(file.path(getwd(), "../data", "time_series.csv"))
data$pickup_date <- as.Date(data$pickup_date)
data <- data[order(data$pickup_date), ]
```

Preprocessing

Train / validation / test split (chronological)

```
HORIZON <- 14   # 14-day forecast (same as ARIMA)
VAL_DAYS <- 30
n <- nrow(data)
test_end <- n
test_start <- test_end - HORIZON
val_end <- test_start
val_start <- val_end - VAL_DAYS
train_end <- val_start

values <- matrix(data$avg_duration_min, ncol = 1)
train_values <- values[1:train_end, , drop = FALSE]
val_values <- values[val_start:(val_end - 1), , drop = FALSE]
test_values <- values[test_start:(test_end - 1), , drop = FALSE]
test_dates <- data$pickup_date[test_start:(test_end - 1)]
```

Scaling

```
min_val <- min(train_values)
max_val <- max(train_values)
scale_fun <- function(x) (x - min_val) / (max_val - min_val)
inv_scale_fun <- function(z) z * (max_val - min_val) + min_val

train_scaled <- scale_fun(train_values)
val_scaled <- scale_fun(val_values)
test_scaled <- scale_fun(test_values)
```

Sequence construction (sliding window)

```r
SEQ_LEN <- 21

create_sequences <- function(scaled_data, seq_len) {
  X <- array(NA, dim = c(nrow(scaled_data) - seq_len, seq_len, 1))
  y <- numeric(nrow(scaled_data) - seq_len)
  for (i in seq_len(nrow(scaled_data) - seq_len)) {
    ii <- i + seq_len - 1
    X[i, , 1] <- scaled_data[i:ii, 1]
    y[i] <- scaled_data[ii + 1, 1]
  }
  list(X = X, y = y)
}

train_val_scaled <- rbind(train_scaled, val_scaled)
seqs <- create_sequences(train_val_scaled, SEQ_LEN)
X_train <- seqs$X
y_train <- seqs$y
```

Model (LSTM)

```r
library(keras)
```

```
The keras package is deprecated. Use the keras3 package instead.
```

```r
inputs <- layer_input(shape = c(SEQ_LEN, 1))
outputs <- inputs %>%
  layer_lstm(units = 32, return_sequences = FALSE) %>%
  layer_dropout(rate = 0.2) %>%
  layer_dense(units = 1)
model <- keras_model(inputs, outputs)

model$compile(
  optimizer = optimizer_adam(),
  loss = "mse"
)
```

Training

```r
library(tensorflow)
# Use 20% of training sequences as validation for early stopping
val_idx <- sample(length(y_train), size = round(0.2 * length(y_train)))
x_val <- X_train[val_idx, , , drop = FALSE]
y_val <- y_train[val_idx]
x_fit <- X_train[-val_idx, , , drop = FALSE]
y_fit <- y_train[-val_idx]
```

```
np <- reticulate::import("numpy")
x_fit_tf <- tf$constant(np$array(x_fit, dtype = np$float32))
y_fit_tf <- tf$constant(np$array(y_fit, dtype = np$float32))
x_val_tf <- tf$constant(np$array(x_val, dtype = np$float32))
y_val_tf <- tf$constant(np$array(y_val, dtype = np$float32))

history <- model$fit(
  x_fit_tf, y_fit_tf,
  epochs = 100L,
  batch_size = 16L,
  validation_data = list(x_val_tf, y_val_tf),
  callbacks = list(
    callback_early_stopping(monitor = "val_loss", patience = 15, restore_best_weights = TRUE)
  ),
  verbose = 1
)
```

```
Epoch 1/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m11s[0m 713ms/step - loss: 0.3498
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1s[0m 12ms/step - loss: 0.1420 -
val_loss: 0.0273
Epoch 2/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 32ms/step - loss: 0.0534
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0392 -
val_loss: 0.0293
Epoch 3/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 32ms/step - loss: 0.0474
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0342 -
val_loss: 0.0259
Epoch 4/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 25ms/step - loss: 0.0484
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0330 -
val_loss: 0.0259
Epoch 5/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 20ms/step - loss: 0.0304
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0323 -
val_loss: 0.0265
Epoch 6/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0276
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0332 -
val_loss: 0.0258
Epoch 7/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0272
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0312 -
```

```
val_loss: 0.0265
Epoch 8/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0176
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 6ms/step - loss: 0.0338 -
val_loss: 0.0258
Epoch 9/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 14ms/step - loss: 0.0341
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0305 -
val_loss: 0.0265
Epoch 10/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0262
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0321 -
val_loss: 0.0259
Epoch 11/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 19ms/step - loss: 0.0223
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0301 -
val_loss: 0.0259
Epoch 12/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0183
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0325 -
val_loss: 0.0258
Epoch 13/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0357
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0283 -
val_loss: 0.0260
Epoch 14/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 26ms/step - loss: 0.0289
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0256 -
val_loss: 0.0257
Epoch 15/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0248
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0297 -
val_loss: 0.0264
Epoch 16/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 27ms/step - loss: 0.0231
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0281 -
val_loss: 0.0256
Epoch 17/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 26ms/step - loss: 0.0311
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0269 -
val_loss: 0.0257
```

```
Epoch 18/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 27ms/step - loss: 0.0244
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0278 -
val_loss: 0.0278
Epoch 19/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 16ms/step - loss: 0.0288
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0296 -
val_loss: 0.0258
Epoch 20/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 15ms/step - loss: 0.0268
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0286 -
val_loss: 0.0258
Epoch 21/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 16ms/step - loss: 0.0172
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0262 -
val_loss: 0.0306
Epoch 22/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m1s[0m 73ms/step - loss: 0.0169
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0306 -
val_loss: 0.0254
Epoch 23/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 22ms/step - loss: 0.0269
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 6ms/step - loss: 0.0269 -
val_loss: 0.0254
Epoch 24/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 16ms/step - loss: 0.0271
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0275 -
val_loss: 0.0254
Epoch 25/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 15ms/step - loss: 0.0328
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0283 -
val_loss: 0.0253
Epoch 26/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 32ms/step - loss: 0.0307
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 5ms/step - loss: 0.0266 -
val_loss: 0.0256
Epoch 27/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1m0s[0m 15ms/step - loss: 0.0360
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 3ms/step - loss: 0.0284
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m1m0s[0m 6ms/step - loss: 0.0261 -
val_loss: 0.0252
```

```
Epoch 28/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 20ms/step - loss: 0.0249
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0282 -
val_loss: 0.0254
Epoch 29/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0130
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0262 -
val_loss: 0.0250
Epoch 30/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 22ms/step - loss: 0.0226
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0270 -
val_loss: 0.0263
Epoch 31/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0432
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0298 -
val_loss: 0.0259
Epoch 32/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1s[0m 81ms/step - loss: 0.0157
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0254 -
val_loss: 0.0249
Epoch 33/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 8ms/step - loss: 0.0282
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0272 -
val_loss: 0.0254
Epoch 34/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0377
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0281 -
val_loss: 0.0258
Epoch 35/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0301
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0264 -
val_loss: 0.0248
Epoch 36/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 14ms/step - loss: 0.0260
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0271 -
val_loss: 0.0256
Epoch 37/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0330
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0278 -
val_loss: 0.0257
Epoch 38/100
```

```
[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 6ms/step - loss: 0.0196
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0265 -
val_loss: 0.0247
Epoch 39/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0192
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0271 -
val_loss: 0.0247
Epoch 40/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0212
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0277 -
val_loss: 0.0263
Epoch 41/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0283
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0254 -
val_loss: 0.0252
Epoch 42/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 22ms/step - loss: 0.0155
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0268 -
val_loss: 0.0244
Epoch 43/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0183
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0270 -
val_loss: 0.0255
Epoch 44/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 27ms/step - loss: 0.0243
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0262 -
val_loss: 0.0245
Epoch 45/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 14ms/step - loss: 0.0128
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0247 -
val_loss: 0.0242
Epoch 46/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 12ms/step - loss: 0.0250
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0265 -
val_loss: 0.0243
Epoch 47/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 21ms/step - loss: 0.0252
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0259 -
val_loss: 0.0244
Epoch 48/100
```

```
[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0303
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0258 -
val_loss: 0.0240
Epoch 49/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 13ms/step - loss: 0.0223
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0253 -
val_loss: 0.0245
Epoch 50/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m1s[0m 92ms/step - loss: 0.0108
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0239 -
val_loss: 0.0243
Epoch 51/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 31ms/step - loss: 0.0204
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0245 -
val_loss: 0.0239
Epoch 52/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 14ms/step - loss: 0.0256
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0244 -
val_loss: 0.0240
Epoch 53/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 17ms/step - loss: 0.0389
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0265 -
val_loss: 0.0238
Epoch 54/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 1ms/step - loss: 0.0193
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 3ms/step - loss: 0.0225
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0240 -
val_loss: 0.0245
Epoch 55/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0198
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0253 -
val_loss: 0.0237
Epoch 56/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0190
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0265 -
val_loss: 0.0236
Epoch 57/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0102
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0267 -
val_loss: 0.0236
Epoch 58/100
```

```
[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 28ms/step - loss: 0.0366
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0245 -
val_loss: 0.0236
Epoch 59/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 3ms/step - loss: 0.0193
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0257 -
val_loss: 0.0233
Epoch 60/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0280
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0258 -
val_loss: 0.0232
Epoch 61/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0277
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0268 -
val_loss: 0.0259
Epoch 62/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0323
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0245 -
val_loss: 0.0233
Epoch 63/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 4ms/step - loss: 0.0108
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0237 -
val_loss: 0.0237
Epoch 64/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0199
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0260 -
val_loss: 0.0233
Epoch 65/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 17ms/step - loss: 0.0222
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0232 -
val_loss: 0.0253
Epoch 66/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 14ms/step - loss: 0.0282
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0258 -
val_loss: 0.0227
Epoch 67/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 18ms/step - loss: 0.0092
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0267 -
val_loss: 0.0225
Epoch 68/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 17ms/step - loss: 0.0319
```

```
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0241 -
val_loss: 0.0224
Epoch 69/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 22ms/step - loss: 0.0351
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0255 -
val_loss: 0.0230
Epoch 70/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0293
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0239 -
val_loss: 0.0222
Epoch 71/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0196
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0231 -
val_loss: 0.0224
Epoch 72/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0297
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0229 -
val_loss: 0.0227
Epoch 73/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 14ms/step - loss: 0.0246
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0237 -
val_loss: 0.0220
Epoch 74/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 20ms/step - loss: 0.0172
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0227 -
val_loss: 0.0219
Epoch 75/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 7ms/step - loss: 0.0188
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0229 -
val_loss: 0.0218
Epoch 76/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0154
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0229 -
val_loss: 0.0220
Epoch 77/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0219
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0227 -
val_loss: 0.0217
Epoch 78/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 12ms/step - loss: 0.0226
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0234 -
```

```
val_loss: 0.0215
Epoch 79/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0263
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0208 -
val_loss: 0.0213
Epoch 80/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 13ms/step - loss: 0.0206
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0237 -
val_loss: 0.0213
Epoch 81/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0175
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0221 -
val_loss: 0.0212
Epoch 82/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 20ms/step - loss: 0.0306
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0235 -
val_loss: 0.0211
Epoch 83/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 6ms/step - loss: 0.0447
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0215 -
val_loss: 0.0210
Epoch 84/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 9ms/step - loss: 0.0187
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0212 -
val_loss: 0.0217
Epoch 85/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 22ms/step - loss: 0.0319
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0229 -
val_loss: 0.0234
Epoch 86/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 9ms/step - loss: 0.0117
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0207 -
val_loss: 0.0209
Epoch 87/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 20ms/step - loss: 0.0239
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0201 -
val_loss: 0.0205
Epoch 88/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 7ms/step - loss: 0.0187
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0212 -
val_loss: 0.0205
```

```
Epoch 89/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0193
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0212 -
val_loss: 0.0204
Epoch 90/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 19ms/step - loss: 0.0078
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0199 -
val_loss: 0.0205
Epoch 91/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0236
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0190 -
val_loss: 0.0203
Epoch 92/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0173
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0193 -
val_loss: 0.0207
Epoch 93/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 23ms/step - loss: 0.0092
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0197 -
val_loss: 0.0201
Epoch 94/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0180
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0180 -
val_loss: 0.0201
Epoch 95/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 21ms/step - loss: 0.0128
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0161 -
val_loss: 0.0203
Epoch 96/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 20ms/step - loss: 0.0246
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0177 -
val_loss: 0.0207
Epoch 97/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 15ms/step - loss: 0.0185
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 4ms/step - loss: 0.0163 -
val_loss: 0.0212
Epoch 98/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 24ms/step - loss: 0.0166
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 3ms/step - loss: 0.0175
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0179 -
val_loss: 0.0211
```

```
Epoch 99/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 16ms/step - loss: 0.0160
[1m15/17[0m [32m━━━━━━━━━━━━━━━━━[0m[37m━━━[0m [1m0s[0m 4ms/step - loss: 0.0174
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0169 -
val_loss: 0.0212
Epoch 100/100

[1m 1/17[0m [32m━[0m[37m━━━━━━━━━━━━━━━━━━━[0m [1m0s[0m 31ms/step - loss: 0.0083
[1m17/17[0m [32m━━━━━━━━━━━━━━━━━━━[0m[37m[0m [1m0s[0m 5ms/step - loss: 0.0163 -
val_loss: 0.0217
```

14-day forecast

```
last_seq <- values[(test_start - SEQ_LEN):(test_start - 1), , drop = FALSE]
last_seq_scaled <- scale_fun(last_seq)
forecast_scaled <- numeric(HORIZON)
current <- last_seq_scaled

for (h in seq_len(HORIZON)) {
  x_h <- array(current, dim = c(1, SEQ_LEN, 1))
  pred <- model$predict(x_h, verbose = 0L)
  forecast_scaled[h] <- as.numeric(pred)[1]
  current <- rbind(current[-1, , drop = FALSE], pred[1, 1])
}

forecast <- inv_scale_fun(forecast_scaled)
forecast_df <- data.frame(
  date = test_dates,
  actual = as.numeric(test_values),
  forecast = forecast
)
forecast_df
```

```
         date actual forecast
1  2024-12-17     22 21.50040
2  2024-12-18     22 21.84176
3  2024-12-19     22 21.64268
4  2024-12-20     22 21.11362
5  2024-12-21     20 20.66760
6  2024-12-22     20 20.53889
7  2024-12-23     21 20.66774
8  2024-12-24     19 20.85355
9  2024-12-25     18 20.92268
10 2024-12-26     19 20.82642
11 2024-12-27     19 20.64139
12 2024-12-28     19 20.48677
13 2024-12-29     19 20.42790
14 2024-12-30     19 20.44953
```

```
out_path <- file.path(getwd(), "../data", "lstm_forecast_14day.csv")
write.csv(forecast_df, out_path, row.names = FALSE)
```

Evaluation: sMAPE and MASE

```
library(Metrics)
library(yardstick)
```

```
Attaching package: 'yardstick'

The following objects are masked from 'package:Metrics':

    accuracy, mae, mape, mase, precision, recall, rmse, smape

The following object is masked from 'package:keras':

    get_weights
```

```
mae_train <- mean(abs(diff(as.numeric(train_values))))
lstm_smape <- Metrics::smape(forecast_df$actual, forecast_df$forecast) * 100
lstm_mase <- yardstick::mase_vec(
  truth = forecast_df$actual,
  estimate = forecast_df$forecast,
  m = 1,
  mae_train = mae_train
)

cat("LSTM sMAPE (%):", round(lstm_smape, 4), "\n")
```

```
LSTM sMAPE (%): 5.7286
```

```
cat("LSTM MASE:", round(lstm_mase, 4), "\n")
```

```
LSTM MASE: 1.4602
```