Proposed Market Making Strategy

I. Objective:

- Make use of our RNN predictions for the next mid-price move.

II. Signal:

- When a mid-price movement occurs, we wait until the bid-ask spread reverts back to 1-tick and then keep track of a running sum of our RNN predictions for the next mid-price move.
- When this signal is positive, we expect an upward mid-price movement, when the signal is negative, we expect a decline in mid-price on the next move. We decide what to do at a given time based on our signal.
- After each mid-price move, we reset our signal to 0.
- Note that for purposes of the proposed strategy, we define a mid-price movement as an increase or decrease in the mid-price and a simultaneous increase (or constant change) in the bid-ask spread. Movements in mid-price where the bid-ask spread decreases are ignored.

III. Strategy:

We begin by placing orders for a single lot (100 shares) on levels 2 - 5 for both bids and asks in order to gain valuable queue position as some of these orders move to the inside market. In the tables and descriptions below, we refer to bid_m (ask_m) as bid (ask) information at level m. So initially our current state may look like:

State 0: Initial State

Level:	bid_5	bid_4	bid_3	bid_2	bid_1	ask_1	ask_2	ask_3	ask_4	ask_5
Price:	25.51	25.52	25.53	25.54	25.55	25.56	25.57	25.58	25.59	25.60
Orders:	1	1	1	1	0	0	1	1	1	1

Now we wait until the first mid-price movement. In our example above, suppose the inside ask level is taken out and we have an upward mid-price movement. The ask_2 then becomes the best ask and we now place a new order on ask_5 at price 25.61:

State 1: 2_Tick State

Level:	bid_5	bid_4	bid_3	bid_2	bid_1	**ask_1**	ask_2	ask_3	ask_4	**ask_5**
Price:	25.51	25.52	25.53	25.54	25.55	**25.57**	25.58	25.59	25.60	**25.61**
Orders:	1	1	1	1	0	**1**	1	1	1	**1**

Now the current bid-ask spread is 2 ticks wide (25.57 - 25.55). During this state we do not place any new orders on the inside market, and any filled orders are closed as fast as

possible. The recently executed order is not replaced yet as the new order would not be in good queue position.

- We wait until the level 25.56 first appears. The 25.56 level may appear as either a bid or an ask level. We then begin to look at our mid-price movement signal from this point on.
- We would then like to immediately place an order on this new level, hoping to gain a valuable queue position. Suppose 25.56 first appears as a bid level as in the example below. The question is should we place an order here?

State 2: Decision State

Level:	bid_5	bid_4	bid_3	bid_2	**bid_1**	**ask_1**	ask_2	ask_3	ask_4	ask_5
Price:	25.52	25.53	25.54	25.55	**25.56**	**25.57**	25.58	25.59	25.60	25.61
Orders:	1	1	1	1	**??**	**1**	1	1	1	1

- Outcome 1: If we predict a downward move (our signal is negative), we do not place a bid_1 order and keep our ask_1 order open.
- Outcome 2: If we predict an up move (our signal is positive), we place a bid_1 order and at the same time cancel the ask_1 order.

Outcome 1: From "State 2," do not place bid_1 order at 25.56 and keep ask_1 order open:

We are currently here:

State 3 - 1: Single active inside order, no position

Level:	bid_5	bid_4	bid_3	bid_2	**bid_1**	**ask_1**	ask_2	ask_3	ask_4	ask_5
Price:	25.52	25.53	25.54	25.55	**25.56**	**25.57**	25.58	25.59	25.60	25.61
Orders:	1	1	1	1	**0**	**1**	1	1	1	1

Here we do not place a bid_1 order in the "State 2" table and we expect a downward mid-price movement. In this case, we wait until one of 2 things happen, either the mid-price moves down, or our ask_1 order is filled:

- If the mid-price moves down, we do not lose the spread, as we did not have an open bid_1 order. In this case bid_2 becomes bid_1 and we return back to "State 1" table above.
- If our ask_1 order is filled first, we are short 1 lot of the asset and reach the below state:

State 3 - 2: Inside order filled, long (short) asset

Level:	bid_5	bid_4	bid_3	bid_2	bid_1	**ask_1**	ask_2	ask_3	ask_4	ask_5
Price:	25.52	25.53	25.54	25.55	25.56	**25.57**	25.58	25.59	25.60	25.61
Orders:	1	1	1	1	0	**0**	1	1	1	1

The above looks like "State 0" only this time we are short 1 lot (as opposed to no position). In this scenario, we again look at our signal.

- If we now predict an upward move, we close out our short position at the same price we opened the position, and make 0 spreads. We return to "State 0" table above.
- If we continue to predict a downward move, we place a bid_1 order at 25.56. We now wait until either our bid_1 order is filled, or the mid-price moves up:
    - If the bid_1 order is filled, we make the spread and return to a similar state as "State 0."
    - If the mid-price moves up, we close our short position, lose at least 1 spread, and return to a similar state as "State 1."

Outcome 2: From "State 2," place bid_1 order at 25.56 and cancel ask_1 order:

We are currently here:

Single active inside order, no position. Same as "State 3 - 1"

Level:	bid_5	bid_4	bid_3	bid_2	**bid_1**	**ask_1**	ask_2	ask_3	ask_4	ask_5
Price:	25.52	25.53	25.54	25.55	**25.56**	**25.57**	25.58	25.59	25.60	25.61
Orders:	1	1	1	1	**1**	**0**	1	1	1	1

From "State 2" we placed a bid_1 order and canceled our ask_1 order. We then wait until either the bid_1 order is executed, or the mid-price moves up. The above is identical to "State 3 - 1" only this time we have an open bid_1 order instead of an ask_1 order. We follow directions from "State 3 - 1."

Other States:

There is a possibility we may go from "State 1" to the following state, usually if an open level 1 order is executed before the tick size reverts back to 1.

State 4: 2_Tick State, No level 1 open orders

Level:	bid_5	bid_4	bid_3	bid_2	bid_1	**ask_1**	ask_2	ask_3	ask_4	ask_5
Price:	25.51	25.52	25.53	25.54	25.55	**25.57**	25.58	25.59	25.60	25.61
Orders:	1	1	1	1	0	**0**	1	1	1	1

If we reach this state, we simply wait until the level 25.56 appears.

- Suppose level 25.56 becomes the bid_1 level, then 25.55 moves to bid_2. We place an order on the 25.55 bid_2 and return to a state similar to "State 0."
- Suppose level 25.56 becomes the ask_1 level, then 25.57 moves to ask_2. We place an order on ask_2 and return to a state similar to "State 0."

****Note:** There is always a possibility that the mid-price moves during the short amount of time we need to place and cancel orders due to latency or market orders. In this case, if some orders are executed, we close out all open positions and generally suffer a loss of 1 tick or more. There is also the slight possibility of making a lucky profit in this case if both a bid_1 and an ask_1 order are filled before the mid-price movement.

IV. Out of Sample Strategy Performance:

Below are cumulative PNL plots for our RNN predictions and the above strategy, plotted for different latency times. The latency refers to the time delay in receiving updates to the limit order book as well as the delay in opening/cancelling orders.