Traffic Sign Classifier

The goals / steps of this project are the following:

- Load the data set (see below for links to the project data set)
- Explore, summarize, and visualize the data set
- Design, train and test a model architecture
- Use the model to make predictions on new images
- Analyze the softmax probabilities of the new images
- Summarize the results with a written report

Data Set Summary and exploration

1- Provide a basic summary of the data set

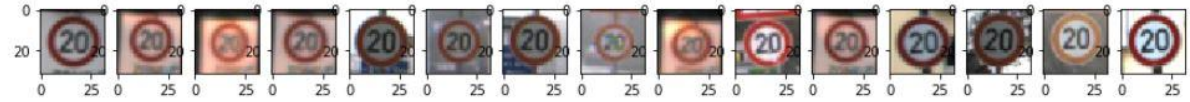
I have loaded the training, validation and testing data set using pickle python library and numpy library to calculate the unique classes/labels for the traffic signs, then calculated some basic information about the traffic signs data set:

- The size of the training set is **34799 images**
- The size of the validation set is **12630 images**
- The size of the testing set is **4410 images**
- The shape of a traffic sign image is **(32x32x3)**
- The number of unique classes/labels in the data set is **43**

2- Include an exploratory visualization of the dataset

Here is an exploratory visualization of samples for the training data set.

----------Training Images Samples----------
Sign: Speed limit (20km/h) Sign_number: 0 - Number of Samples: 180



Sign: Speed limit (30km/h) Sign_number: 1 - Number of Samples: 1980

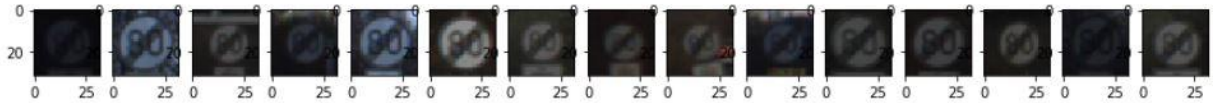
Sign: Speed limit (50km/h) Sign_number: 2 - Number of Samples: 2010

Sign: Speed limit (60km/h) Sign_number: 3 - Number of Samples: 1260

Sign: Speed limit (70km/h) Sign_number: 4 - Number of Samples: 1770

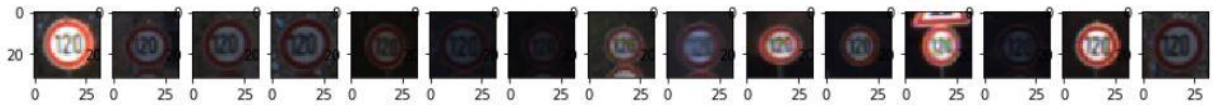
Sign: Speed limit (80km/h) Sign_number: 5 - Number of Samples: 1650

Sign: End of speed limit (80km/h) Sign_number: 6 - Number of Samples: 360

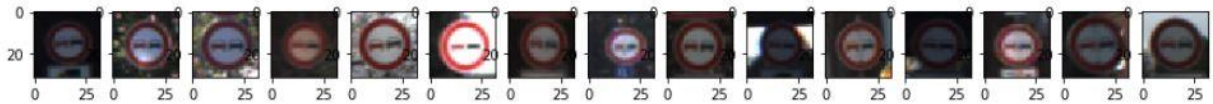


Sign: Speed limit (100km/h) Sign_number: 7 - Number of Samples: 1290

Sign: Speed limit (120km/h) Sign_number: 8 - Number of Samples: 1260



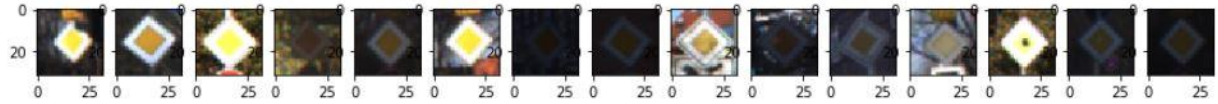
Sign: No passing Sign_number: 9 - Number of Samples: 1320



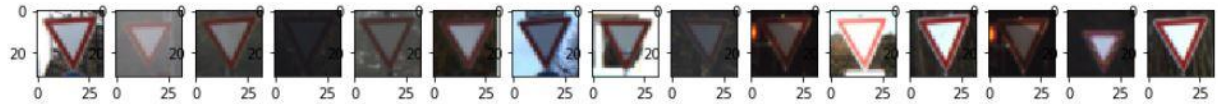
Sign: No passing for vehicles over 3.5 metric tons Sign_number: 10 - Number of Samples: 1800

Sign: Right-of-way at the next intersection Sign_number: 11 - Number of Samples: 1170

Sign: Priority road Sign_number: 12 - Number of Samples: 1890

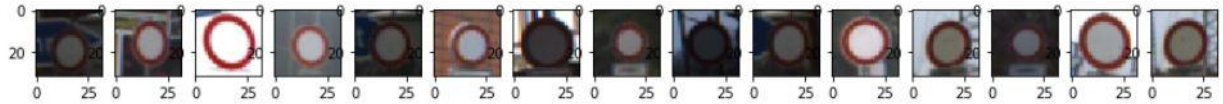


Sign: Yield Sign_number: 13 - Number of Samples: 1920

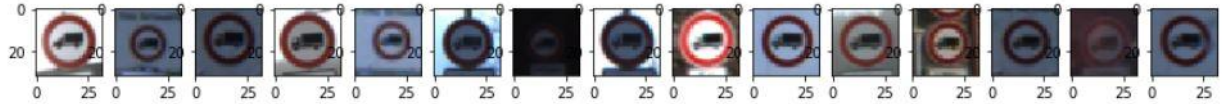


Sign: Stop Sign_number: 14 - Number of Samples: 690

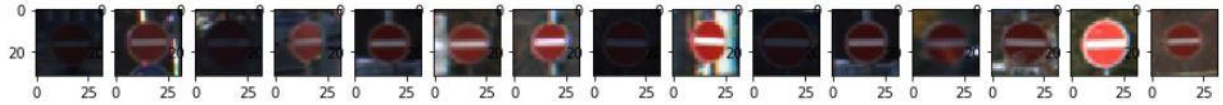
Sign: No vehicles Sign_number: 15 - Number of Samples: 540



Sign: Vehicles over 3.5 metric tons prohibited Sign_number: 16 - Number of Samples: 360



Sign: No entry Sign_number: 17 - Number of Samples: 990



Sign: General caution Sign_number: 18 - Number of Samples: 1080

Sign: Dangerous curve to the left Sign_number: 19 - Number of Samples: 180

Sign: Dangerous curve to the right Sign_number: 20 - Number of Samples: 300

Sign: Double curve Sign_number: 21 - Number of Samples: 270

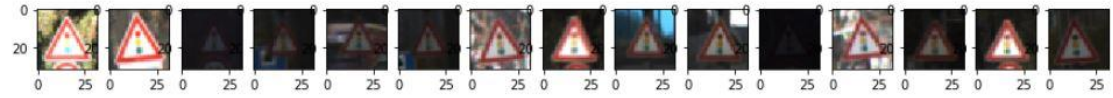
Sign: Bumpy road Sign_number: 22 - Number of Samples: 330

Sign: Slippery road Sign_number: 23 - Number of Samples: 450

Sign: Road narrows on the right Sign_number: 24 - Number of Samples: 240

Sign: Road work Sign_number: 25 - Number of Samples: 1350

Sign: Traffic signals Sign_number: 26 - Number of Samples: 540



Sign: Pedestrians Sign_number: 27 - Number of Samples: 210

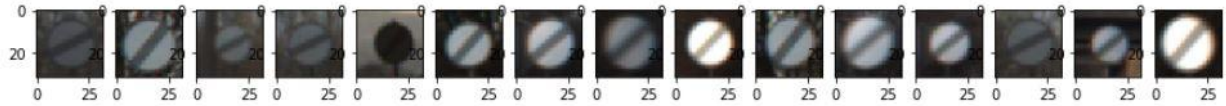
Sign: Children crossing Sign_number: 28 - Number of Samples: 480

Sign: Bicycles crossing Sign_number: 29 - Number of Samples: 240

Sign: Beware of ice/snow Sign_number: 30 - Number of Samples: 390

Sign: Wild animals crossing Sign_number: 31 - Number of Samples: 690

Sign: End of all speed and passing limits Sign_number: 32 - Number of Samples: 210



Sign: Turn right ahead Sign_number: 33 - Number of Samples: 599

Sign: Turn left ahead Sign_number: 34 - Number of Samples: 360

Sign: Ahead only Sign_number: 35 - Number of Samples: 1080

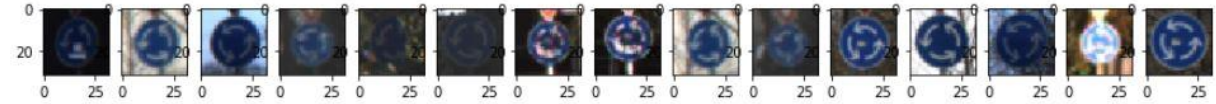
Sign: Go straight or right Sign_number: 36 - Number of Samples: 330

Sign: Go straight or left Sign_number: 37 - Number of Samples: 180

Sign: Keep right Sign_number: 38 - Number of Samples: 1860

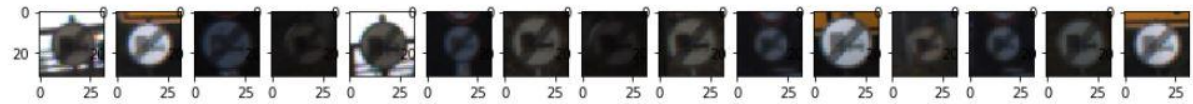
Sign: Keep left Sign_number: 39 - Number of Samples: 270

Sign: Roundabout mandatory Sign_number: 40 - Number of Samples: 300

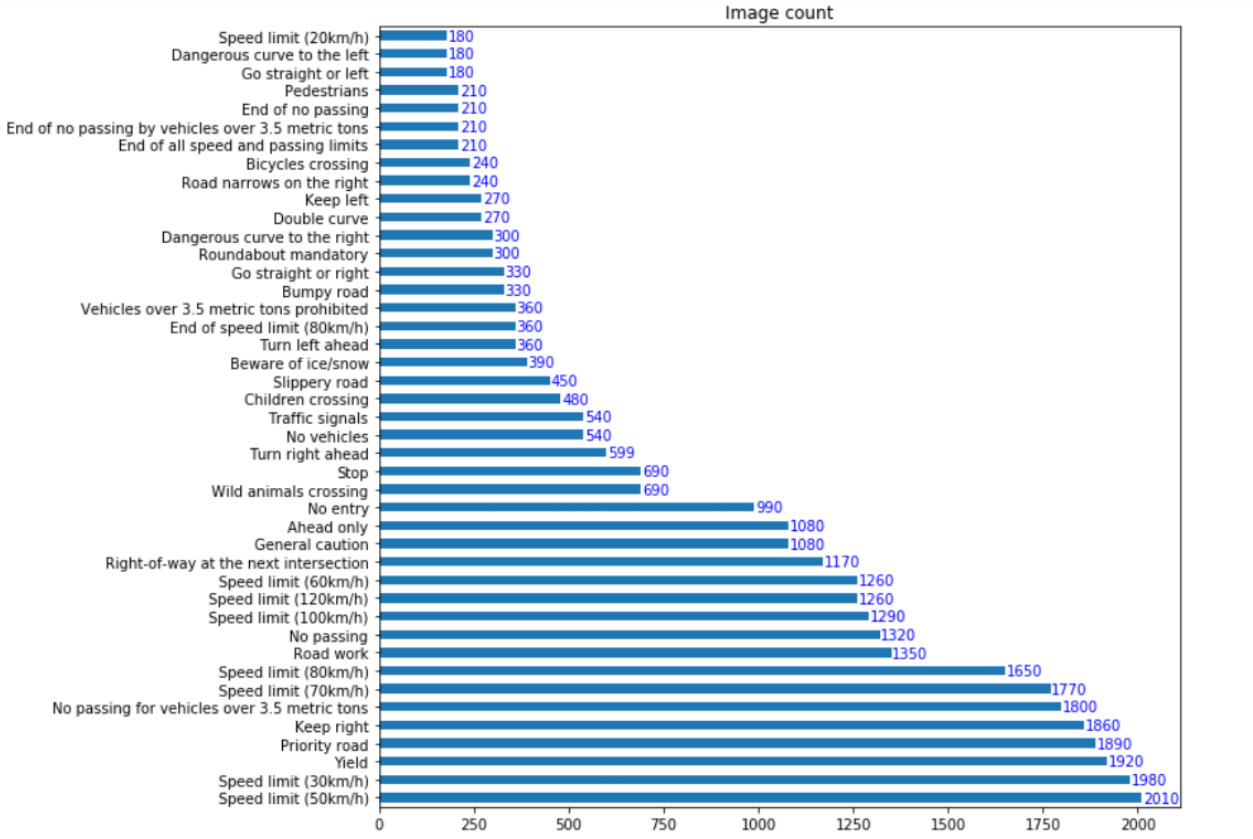


Sign: End of no passing Sign_number: 41 - Number of Samples: 210

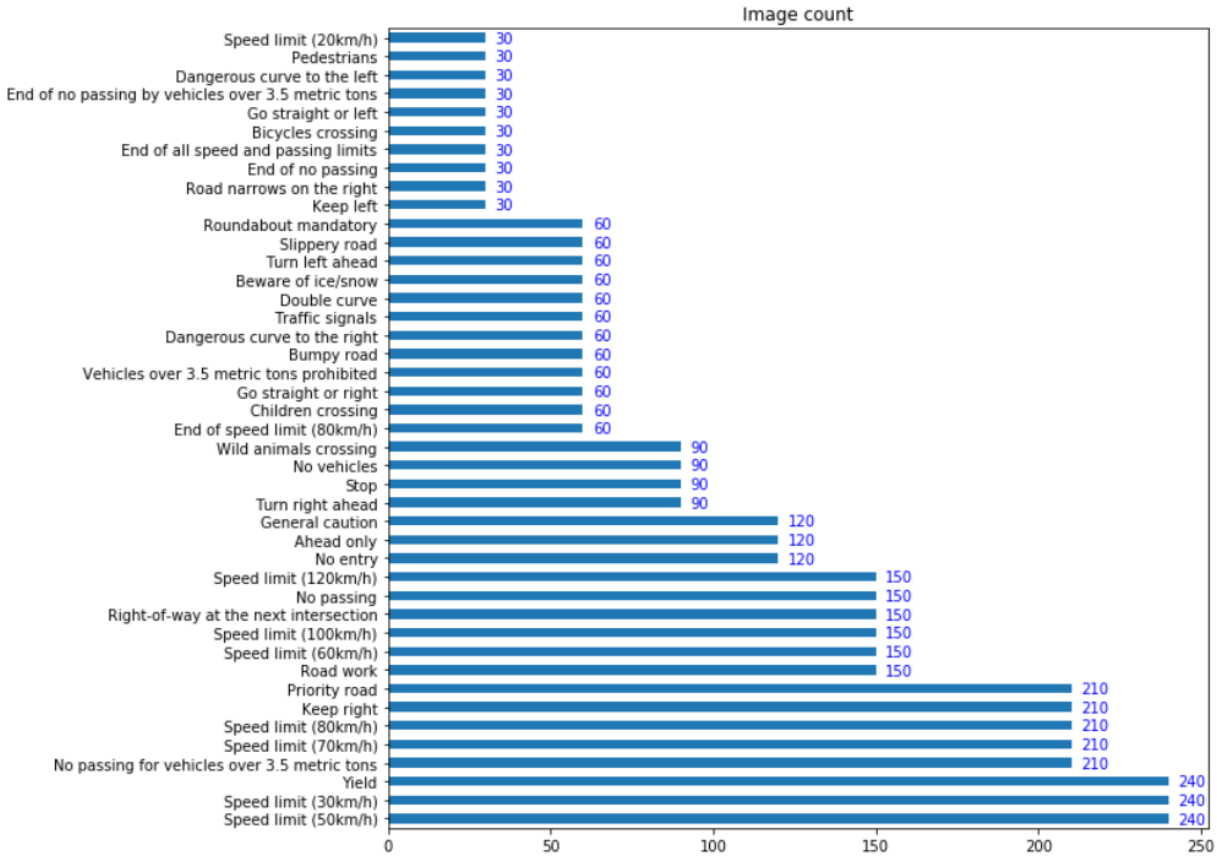
Sign: End of no passing by vehicles over 3.5 metric tons Sign_number: 42 - Number of Samples: 210



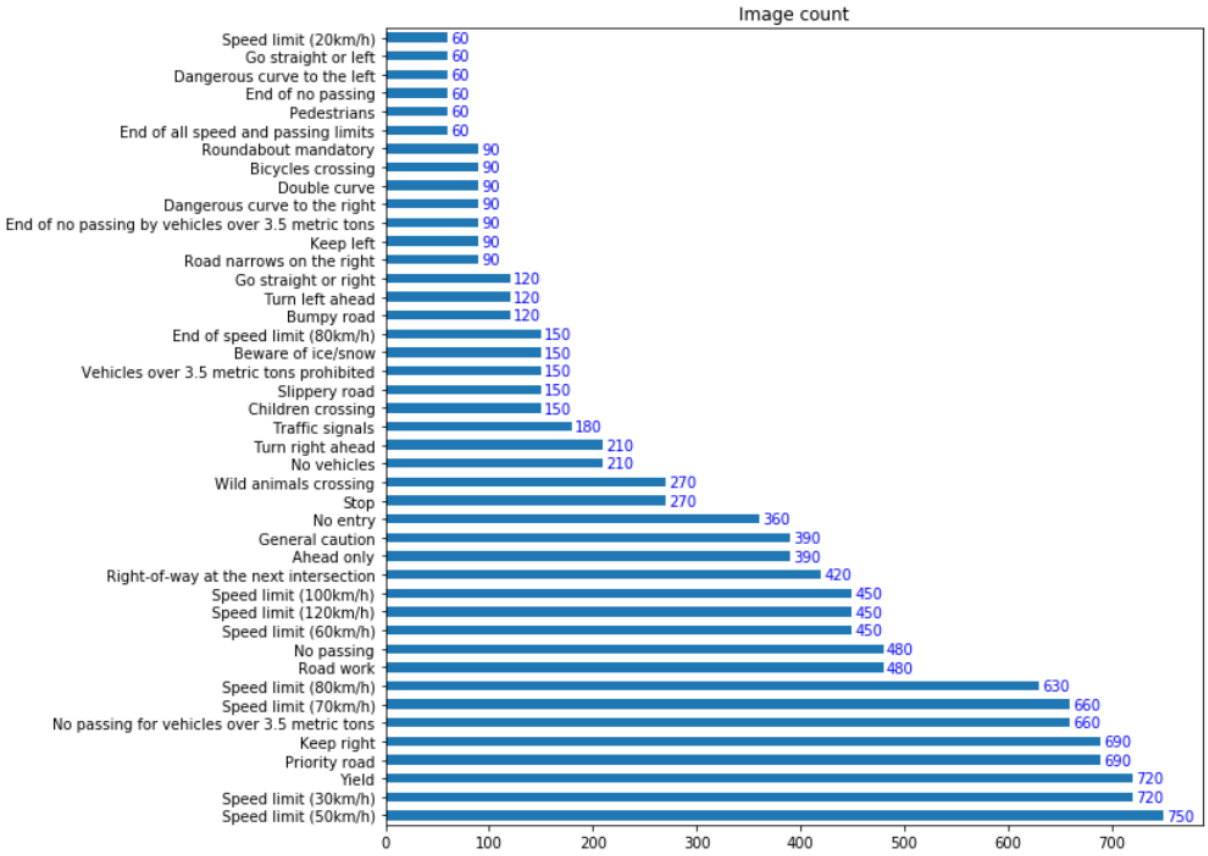
Here a bar chart or a histogram for the training data that shows the number of images in each traffic sign label:



Here a bar chart or a histogram for the validation data that shows the number of images in each traffic sign label:



Here a bar chart or a histogram for the testing data that shows the number of images in each traffic sign label:

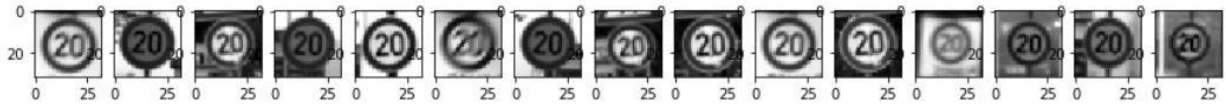


Design and test the Model Architecture

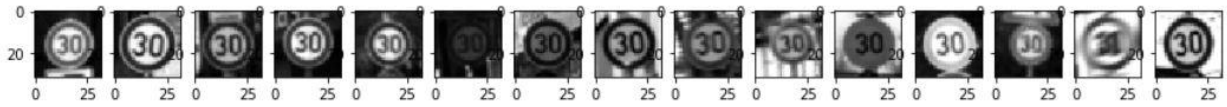
1- Preprocessing phase

As a first step, I decided to convert the images to grayscale this in order to remove the color information from the images for the aim of generalization well for these images. Here is an exploratory visualization of samples for the training data set after the grayscale conversion for the images.

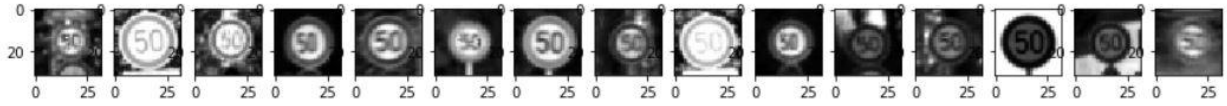
----------Training Images Samples----------
Sign: Speed limit (20km/h) Sign_number: 0 - Number of Samples: 180



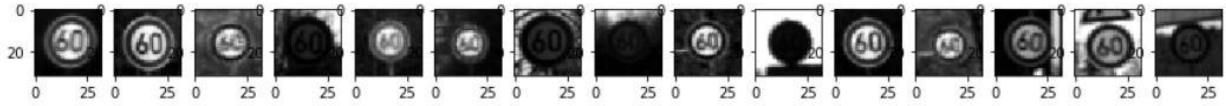
Sign: Speed limit (30km/h) Sign_number: 1 - Number of Samples: 1980



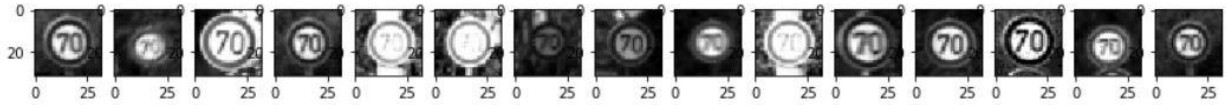
Sign: Speed limit (50km/h) Sign_number: 2 - Number of Samples: 2010



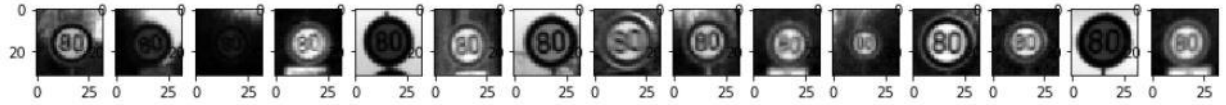
Sign: Speed limit (60km/h) Sign_number: 3 - Number of Samples: 1260



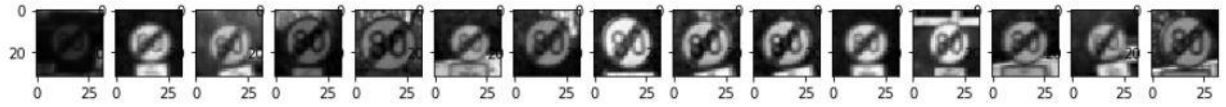
Sign: Speed limit (70km/h) Sign_number: 4 - Number of Samples: 1770



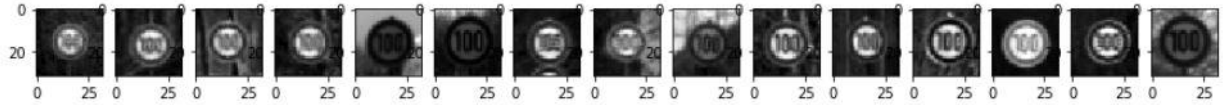
Sign: Speed limit (80km/h) Sign_number: 5 - Number of Samples: 1650



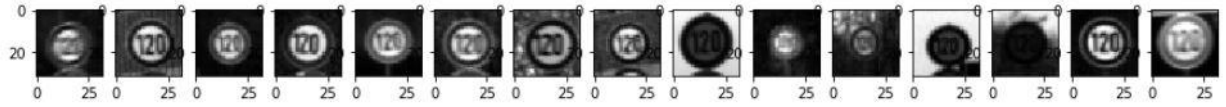
Sign: End of speed limit (80km/h) Sign_number: 6 - Number of Samples: 360



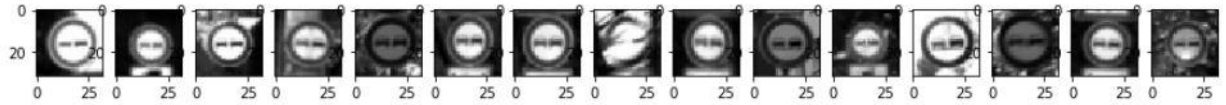
Sign: Speed limit (100km/h) Sign_number: 7 - Number of Samples: 1290



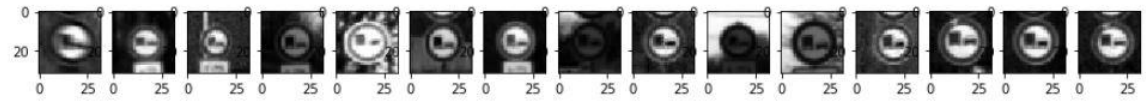
Sign: Speed limit (120km/h) Sign_number: 8 - Number of Samples: 1260



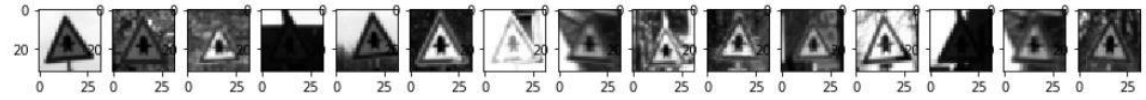
Sign: No passing Sign_number: 9 - Number of Samples: 1320



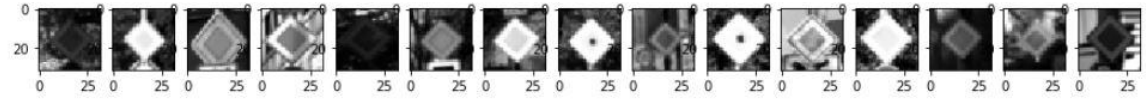
Sign: No passing for vehicles over 3.5 metric tons Sign_number: 10 - Number of Samples: 1800



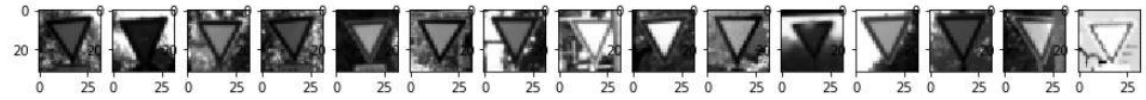
Sign: Right-of-way at the next intersection Sign_number: 11 - Number of Samples: 1170



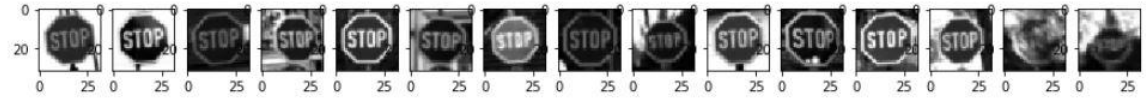
Sign: Priority road Sign_number: 12 - Number of Samples: 1890



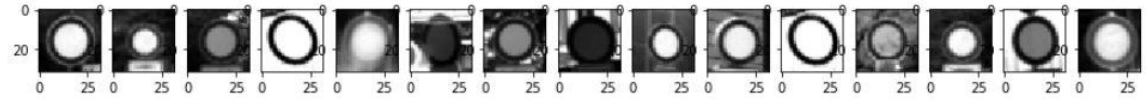
Sign: Yield Sign_number: 13 - Number of Samples: 1920



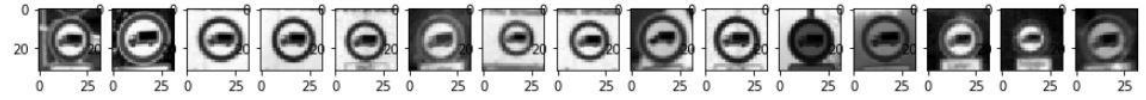
Sign: Stop Sign_number: 14 - Number of Samples: 690



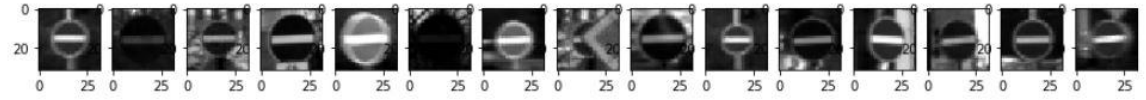
Sign: No vehicles Sign_number: 15 - Number of Samples: 540



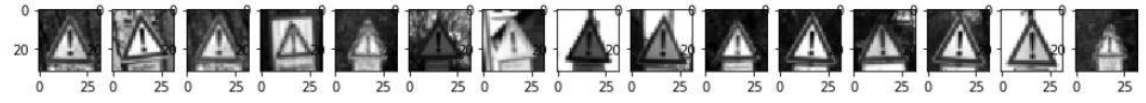
Sign: Vehicles over 3.5 metric tons prohibited Sign_number: 16 - Number of Samples: 360



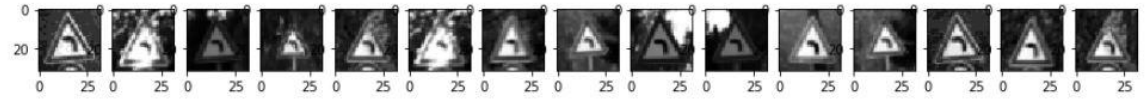
Sign: No entry Sign_number: 17 - Number of Samples: 990



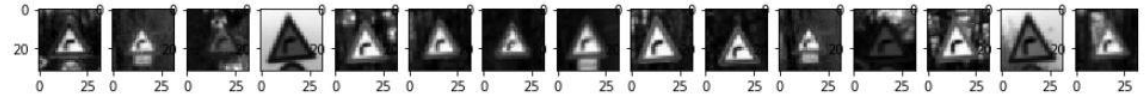
Sign: General caution Sign_number: 18 - Number of Samples: 1080



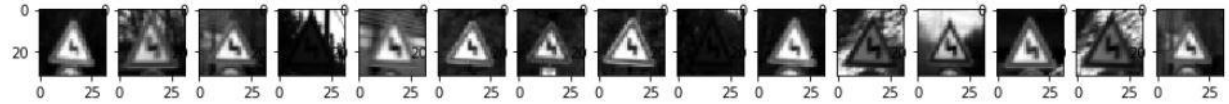
Sign: Dangerous curve to the left Sign_number: 19 - Number of Samples: 180



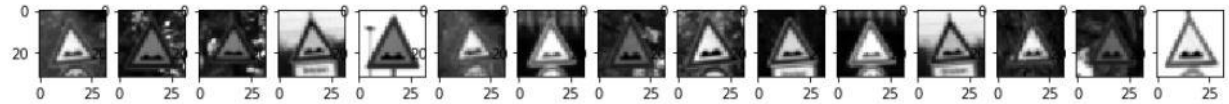
Sign: Dangerous curve to the right Sign_number: 20 - Number of Samples: 300



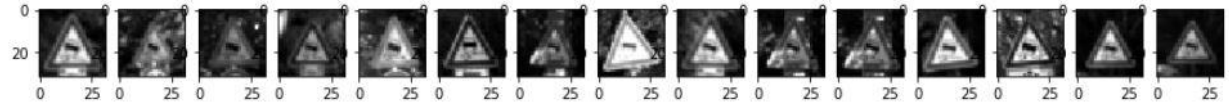
Sign: Double curve Sign_number: 21 - Number of Samples: 270



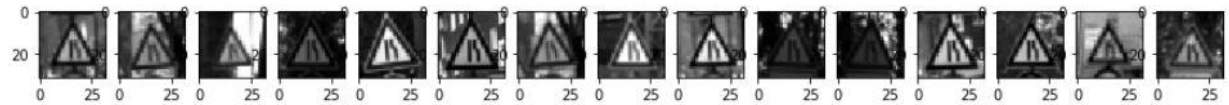
Sign: Bumpy road Sign_number: 22 - Number of Samples: 330



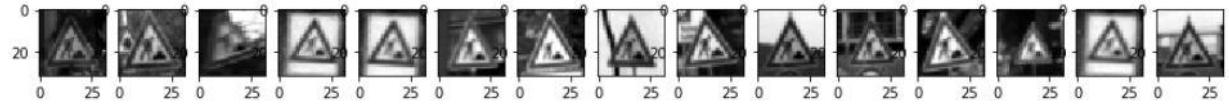
Sign: Slippery road Sign_number: 23 - Number of Samples: 450



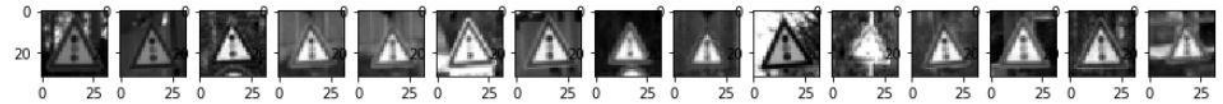
Sign: Road narrows on the right Sign_number: 24 - Number of Samples: 240



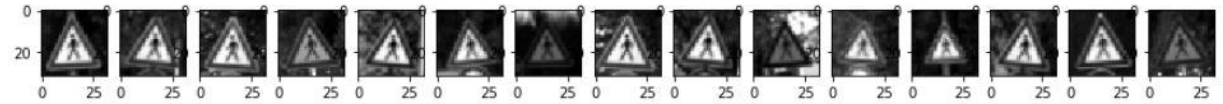
Sign: Road work Sign_number: 25 - Number of Samples: 1350



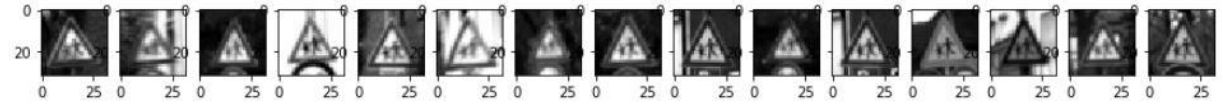
Sign: Traffic signals Sign_number: 26 - Number of Samples: 540



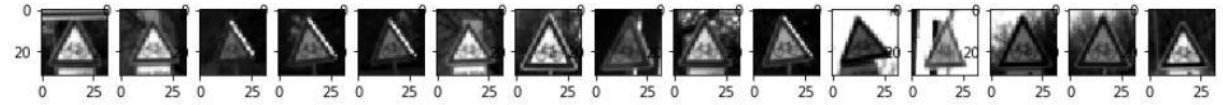
Sign: Pedestrians Sign_number: 27 - Number of Samples: 210



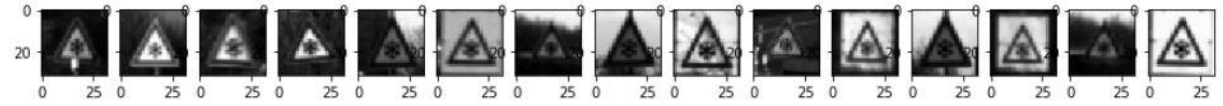
Sign: Children crossing Sign_number: 28 - Number of Samples: 480



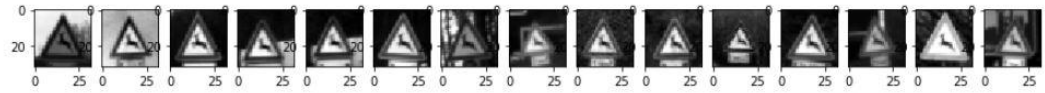
Sign: Bicycles crossing Sign_number: 29 - Number of Samples: 240



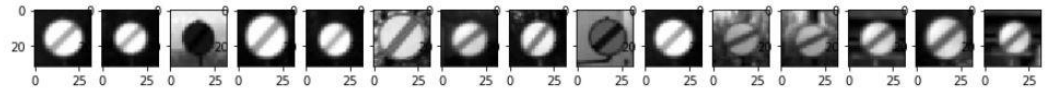
Sign: Beware of ice/snow Sign_number: 30 - Number of Samples: 390



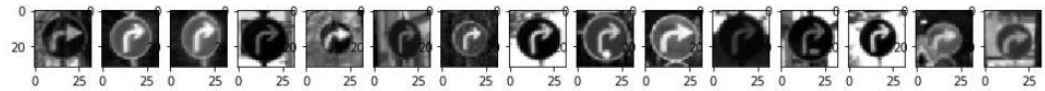
Sign: Wild animals crossing Sign_number: 31 - Number of Samples: 690



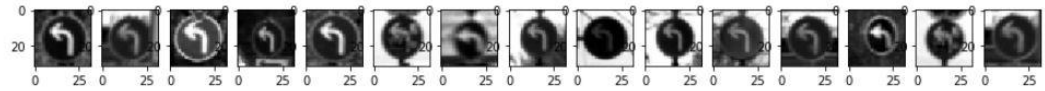
Sign: End of all speed and passing limits Sign_number: 32 - Number of Samples: 210



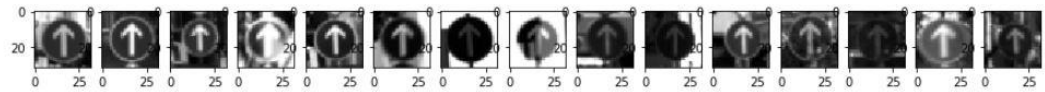
Sign: Turn right ahead Sign_number: 33 - Number of Samples: 599



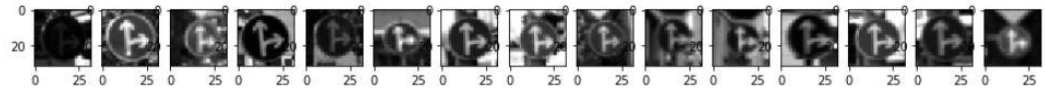
Sign: Turn left ahead Sign_number: 34 - Number of Samples: 360



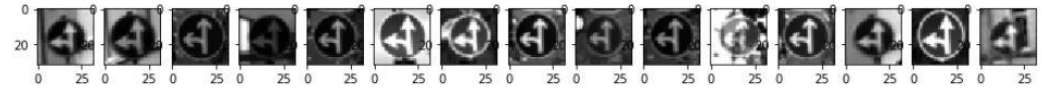
Sign: Ahead only Sign_number: 35 - Number of Samples: 1080



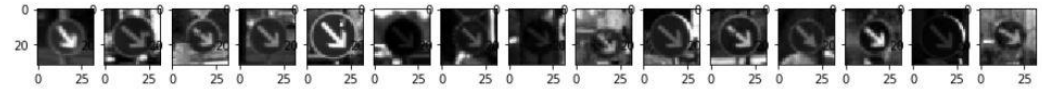
Sign: Go straight or right Sign_number: 36 - Number of Samples: 330



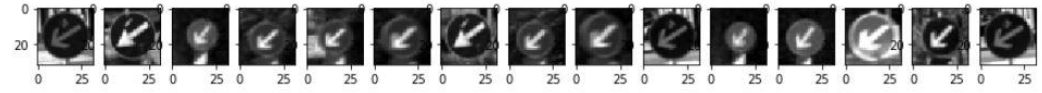
Sign: Go straight or left Sign_number: 37 - Number of Samples: 180



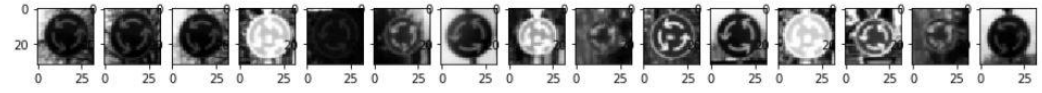
Sign: Keep right Sign_number: 38 - Number of Samples: 1860



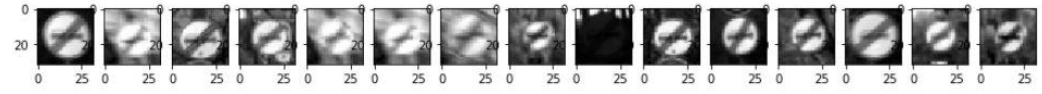
Sign: Keep left Sign_number: 39 - Number of Samples: 270



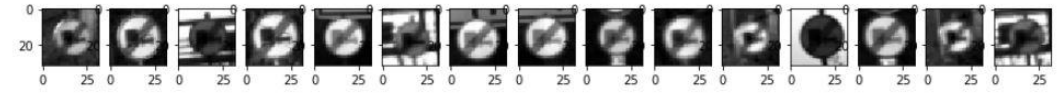
Sign: Roundabout mandatory Sign_number: 40 - Number of Samples: 300



Sign: End of no passing Sign_number: 41 - Number of Samples: 210



Sign: End of no passing by vehicles over 3.5 metric tons Sign_number: 42 - Number of Samples: 210



As a last step, I normalized the image data in order to achieve the same distribution for the whole data which means that the whole data will have the same mean, and variance values.

2- Final Value Architecture

As we know that the LeNet is considered as a strong base for the task of traffic sign classifications, so I used LeNet as a basic implementation for the final architecture with adding some modifications as we will see.

My final model consists of the following layers:

Layer	Description
Input	32x32x1 grayscale image
Convolution 5x5	1x1 stride, Valid padding, outputs 28x28x48
RELU	Activation Function
Max pooling	2x2 stride, outputs 14x14x48
Dropout Regularization	Keep probability = 0.5
Convolution 5x5	1x1 stride, Valid padding, outputs 10x10x96
RELU	Activation Function
Max pooling	2x2 stride, outputs 5x5x96
Dropout Regularization	Keep probability = 0.5
Convolution 5x5	1x1 stride, Valid padding, outputs 3x3x172
RELU	Activation Function
Max pooling	2x2 stride, outputs 2x2x172
Flatten	Flatten 2x2x172 to be 688
Dropout Regularization	Keep probability = 0.5
Fully Connected	Outputs 84
RELU	Activation Function
Dropout Regularization	Keep probability = 0.5
Fully Connected	Outputs 43 (number of classes)

3- Description for how the model was trained

To train the model, I used the following:

- Adam Optimizer with learning rate = **0.0009**
- Batch Size = 128
- Number of epochs = 35
- Keep_prob = 0.5
- Hyper parameters: miu = 0, sigma = 0.1 for the truncated normal initialization of weights.

4- Description for the approach for finding the solution

The approach taken for finding a solution and getting the validation set accuracy to be at least 0.93 is LeNet with some modifications done like: the preprocessing over the input data set, adding a new convolution layer before the concatenation, adding a dropout regularization factor at each layer in the model. We have done some modifications on the LeNet architecture because the accuracy of the validation data set was less than 0.93

My final model results accuracies can be summarized as follows:

- Training set accuracy of **0.999**
- Validation set accuracy of **0.982**1
- Testing set accuracy of **0.963**

These accuracies are calculated in **(Train, Validate and Test the Model)** cells in the IPython notebook.

As this approach depends on LeNet approach, this means that the number of steps needed for this step to converge will be near to its steps. In addition to that, I have run the model initially with larger number of steps, then waited for the accuracies to saturate on a certain value. After that, I have noticed the steps needed to start saturation. This means that I have used the **Early Stopping** approach for choosing the steps number.

Test the model on New Images

1- Choose five German traffic signs

Here are some German traffic signs that I found on the web:

2- Model's Prediction

Here are the results of the prediction:

Image	Prediction
Speed limit (20km/h) 	Speed limit (20km/h) 
Speed limit (30km/h) 	Speed limit (30km/h) 
Speed limit (50km/h) 	Speed limit (50km/h) 
Speed limit (60km/h) 	Speed limit (60km/h) 
Speed limit (100km/h) 	Speed limit (80km/h) 
No passing 	No passing 
No passing 	No passing 
Right-of-way at the next Intersection 	Right-of-way at the next Intersection 
Right-of-way at the next Intersection 	Right-of-way at the next Intersection 
Priority Road 	Priority Road 
Priority Road 	Priority Road 
Yield 	Yield 

Stop 	**Stop** 
No Entry 	**No Entry** 
General caution 	**General caution** 
General caution 	**General caution** 
Dangerous curve to the left 	**Dangerous curve to the left** 
Road Work 	**Road Work** 
Wild Animal crossing 	**Wild Animal crossing** 
End of all speed and passing limit 	**End of all speed and passing limit** 
Ahead only 	**Ahead only** 
Go straight or right 	**Go straight or right** 
Go straight or left 	**Go straight or left** 
Keep Right 	**Keep Right** 
Keep Right 	**General caution** 
Roundabout mandatory 	**Roundabout mandatory** 

The model was able to correctly guess **24 of the 26 traffic signs**, which gives an accuracy of **0.923%**

I have a justification for the second keep right sign which is  . The image doesn't concentrate on the traffic sign itself due to the presence of some background, but the background is not the root cause of that. The root cause is the traffic sign features didn't extracted well. It is obvious that the first keep right traffic sign  is predicted well as the image is concise over the traffic sign itself.

3- Softmax Predictions for the additional Images

For the first image, the model is relatively sure that this is a Speed limit(20km/h) (probability of **0.96769**), and the image does contain a Speed limit(20km/h). The top five soft max probabilities were

Probability	Prediction
0.96769	Speed limit (20km/h)
0.0193717	General caution
0.007938	Speed limit (70km/h)
0.004328	Speed limit (30km/h)
0.00029531	Speed limit (60km/h)

For the Second image, the model is relatively sure that this is a Speed limit(30km/h) (probability of **0.99493**), and the image does contain a Speed limit(30km/h). The top five soft max probabilities were

Probability	Prediction
0.99493	Speed limit (30km/h)
0.004	Speed limit (20km/h)
0.005047	Speed limit (50km/h)
0.0001277	Roundabout mandatory
8.55640101e-05	Speed limit (70km/h)

For the third image, the model is relatively sure that this is a Right-of-way at the next intersection sign (probability of **0.9999**), and the image does contain a Right-of-way at the next intersection. The top five soft max probabilities were

Probability	Prediction
0.9999	Right-of-way at the next intersection
2.43023851e-06	Beware of ice/snow
4.49315030e-10	Pedestrians
4.44944483e-13	Double curve
2.40414432e-13	Roundabout mandatory

For the fourth image, the model is relatively sure that this is a Right-of-way at the next intersection sign (probability of **1.0**), and the image does contain a Right-of-way at the next intersection. The top five soft max probabilities were

Probability	**Prediction**
1.0	Right-of-way at the next intersection
9.69679476e-11	Beware of ice/snow
3.84142825e-15	Pedestrians
1.43944305e-18	Roundabout mandatory
2.32028039e-19	Double curve

For the fifth image, the model is relatively sure that this is a Priority road sign (probability of **1.0**), and the image does contain a Priority road sign. The top five soft max probabilities were

Probability	**Prediction**
1.0	Priority road
2.74372077e-16	Roundabout mandatory
1.23394802e-18	Road work
2.26647811e-20	Keep right
3.49877876e-24	Keep left

For the sixth image, the model is relatively sure that this is a Priority road sign (probability of **1.0**), and the image does contain a Priority road sign. The top five soft max probabilities were

Probability	**Prediction**
1.0	Priority road
8.47423211e-18	Roundabout mandatory
1.49669254e-18	Road work
7.79239396e-19	Keep right
5.85889120e-21	Yield

For the seventh image, the model is relatively sure that this is a Yield sign (probability of **1.0**), and the image does contain a Yield sign. The top five soft max probabilities were

Probability	**Prediction**
1.0	Yield
1.69595591e-25	No vehicles
2.59372747e-27	Priority road
1.18212888e-29	Speed limit (50km/h)
2.15729591e-31	Speed limit (30km/h)

For the eighth image, the model is relatively sure that this is a stop sign (probability of **0.49755**), and the image does contain a stop sign. The top five soft max probabilities were

Probability	**Prediction**
0.49755	Stop
0.16801	Speed limit (30km/h)
0.0499336496	Turn left ahead
0.0471831486	Speed limit (120km/h)
0.0454424061	Speed limit (60km/h)

For the ninth image, the model is relatively sure that this is a No entry sign (probability of **0.99692**), and the image does contain a No entry sign. The top five soft max probabilities were

Probability	**Prediction**
0.996919751	No entry
0.00308020669	Stop
4.36346888e-08	No passing
1.07657492e-08	Ahead only
5.90702265e-10	Speed limit (120km/h)

For the tenth image, the model is relatively sure that this is a General caution sign (probability of **1.0**), and the image does contain a General caution sign. The top five soft max probabilities were

Probability	Prediction
1.0	General caution
4.16148854e-15	Traffic signals
4.28877133e-17	Pedestrians
8.97829721e-20	Right-of-way at the next intersection
1.06401759e-26	Road work

For the eleventh image, the model is relatively sure that this is a Speed General caution sign (probability of **1.0**), and the image does contain a General caution sign. The top five soft max probabilities were

Probability	Prediction
1.0	General caution
2.67478573e-08	Traffic signals
7.99735833e-11	Pedestrians
8.34462274e-13	Right-of-way at the next intersection
3.24678354e-13	Bicycles crossing

For the twelfth image, the model is relatively sure that this is a Dangerous curve to the left sign (probability of **0.9999**), and the image does contain a Dangerous curve to the left sign. The top five soft max probabilities were

Probability	Prediction
0.9999	Dangerous curve to the left
3.09776794e-07	Slippery road
5.50884172e-10	Wild animals crossing
1.25654114e-11	Speed limit (20km/h)
1.23513170e-11	Double curve

For the thirteenth image, the model is relatively sure that this is a Speed limit sign (50km/h) (probability of **0.7969**), and the image does contain a Speed limit sign(50km/h). The top five soft max probabilities were

Probability	Prediction
0.7969	Speed limit (50km/h)
0.104977034	Speed limit (80km/h)
0.0869150609	Speed limit (30km/h)
0.0107664894	Speed limit (60km/h)
0.000224919611	Roundabout mandatory

For the fourteenth image, the model is relatively sure that this is a Road work Sign (probability of **0.9998**), and the image does contain a Road work Sign. The top five soft max probabilities were

Probability	Prediction
0.9998	Road work
1.67459773e-04	Right-of-way at the next intersection
8.39789118e-06	Double curve
1.20701941e-07	Beware of ice/snow
1.03107675e-10	Dangerous curve to the right

For the fifteenth image, the model is relatively sure that this is a Speed limit(60km/h) (probability of **0.99937**), and the image does contain a Speed limit(60km/h). The top five soft max probabilities were

Probability	Prediction
0.99937	Speed limit (60km/h)
6.28302980e-04	Speed limit (80km/h)
5.81938693e-08	Speed limit (50km/h)
2.87324369e-08	No passing
2.38498945e-08	Speed limit (120km/h)

For the sixteenth image, the model is relatively sure that this is a Wild animals crossing sign (probability of **0.98542**), and the image does contain a Wild animals crossing sign. The top five soft max probabilities were

Probability	Prediction
0.98542	Wild animals crossing
0.0139779979	Slippery road
5.91569638e-04	Dangerous curve to the left
1.42527222e-06	Double curve
1.72659441e-07	Bicycles crossing

For the seventeenth image, the model is relatively sure that this is an End of all speed and passing limits sign (probability of **0.99861**), and the image does contain an End of all speed and passing limits sign. The top five soft max probabilities were

Probability	Prediction
0.99861	End of all speed and passing limits
0.00134721084	End of no passing
3.22560481e-05	End of speed limit (80km/h)
2.85940268e-06	General caution
2.28997328e-06	Speed limit (60km/h)

For the eighteenth image, the model is relatively sure that this is Ahead only sign (probability of **1.0**), and the image does contain Ahead only sign. The top five soft max probabilities were

Probability	Prediction
1.0	Ahead only
7.64093717e-14	Turn left ahead
2.06057841e-14	Speed limit (60km/h)
3.82535749e-15	Right-of-way at the next intersection
1.90298742e-15	Go straight or right

For the nineteenth image, the model is relatively sure that this is a Go straight or right sign (probability of **1.0**), and the image does contain a Go straight or right sign. The top five soft max probabilities were

Probability	**Prediction**
1.0	Go straight or right
9.02706176e-09	Ahead only
3.07771114e-10	Turn left ahead
2.03696074e-10	End of all speed and passing limits
3.34314867e-11	Children crossing

For the twentieth image, the model is relatively sure that this is a Speed Go straight or left sign (probability of **1.0**), and the image does contain a Go straight or left sign. The top five soft max probabilities were

Probability	**Prediction**
1.0	Go straight or left
2.93068694e-12	Right-of-way at the next intersection
4.20002134e-14	Priority road
2.14125304e-14	Ahead only
8.86108877e-18	Roundabout mandatory

For the twenty-first image, the model is relatively sure that this is a Keep right sign (probability of **1.0**), and the image does contain a Keep right sign. The top five soft max probabilities were

Probability	**Prediction**
1.0	Keep right
2.87824154e-13	Turn left ahead
3.69105195e-16	Beware of ice/snow
3.05324838e-17	Wild animals crossing
1.04499191e-17	Double curve

For the twenty-second image, the model is relatively sure that this is a General caution sign (probability of **0.73126**), and the image **doesn't** contain a General caution sign as it is a **keep right sign**. The top five soft max probabilities were

Probability	Prediction
0.73126	General caution
0.185049921	Traffic signals
0.0190520957	Pedestrians
8.33022036e-03	Turn right ahead
7.19230063e-03	Road work

For the twenty-third image, the model is relatively sure that this is a Roundabout mandatory sign (probability of **0.584277**), and the image does contain a Roundabout mandatory sign. The top five soft max probabilities were

Probability	Prediction
0.584277	Roundabout mandatory
0.415006191	Priority road
4.38208488e-04	Keep right
8.02435388e-05	Road work
2.86778795e-05	Speed limit (60km/h)

For the twenty-fourth image, the model is relatively sure that this is a Speed limit (80km/h) (probability of **0.50555**), and the image doesn't contain a Speed limit (80km/h) as it is **Speed limit (100km/h)**. The top five soft max probabilities were

Probability	Prediction
0.50555	Speed limit (80km/h)
0.358618826	Speed limit (60km/h)
0.0755442604	No passing for vehicles over 3.5 metric tons
0.0310752615	Vehicles over 3.5 metric tons prohibited
0.0100370832	Speed limit (50km/h)

For the twenty-fifth image, the model is relatively sure that this is a No passing sign (probability of **0.926024**), and the image does contain a stop sign. The top five soft max probabilities were

Probability	Prediction
0.926024	No passing
0.0240340196	No passing for vehicles over 3.5 metric tons
0.0218105484	Vehicles over 3.5 metric tons prohibited
0.0217854921	Speed limit (60km/h)
0.00160254154	Priority road

For the twenty-sixth image, the model is relatively sure that this is a No passing sign (probability of **0.99985**), and the image does contain a No passing sign. The top five soft max probabilities were

Probability	Prediction
0.99985	No passing
6.13386510e-05	No passing for vehicles over 3.5 metric tons
5.49120305e-05	Vehicles over 3.5 metric tons prohibited
2.51378751e-05	Speed limit (60km/h)
4.27430859e-06	End of no passing