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Estimation of Manufacturing Time for Injection Mold Using Artificial Neural Network

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Abstract: The most critical activity in an injection mold engineering industry is project time estimation. This activity is usually done by highly skilled and in-house experts. The purpose of this paper is to establish a manufacturing time estimation model by Artificial Neural Network that will enable product designers to quickly estimate the mold manufacturing time. The paper also focuses on Computer Aided Manufacturing aspects of injection mold. Parameters linked with mold like mold length, width and height, number of cavities, plate thickness are analysed. The outcome of this paper will be an estimation model which can be used for estimating manufacturing time of any random injection mold part mold.

Keywords — Injection Mold, Estimation, Manufacturing Time, Artificial Neural Network, Computer Aided Manufacturing.

I. INTRODUCTION

The product life in today's market condition is short and the biggest challenge the manufacturers face is to reduce the launching time of a new product, without quality complaints. This is a difficult task, independent of the product, without producing one or more tools for the product. Major contribution in product development is of tool planning and production which affects the final price and launching time. Tool making is an important link in the launching of products in the market and estimating the time and price necessary for product development is the key for profitability.

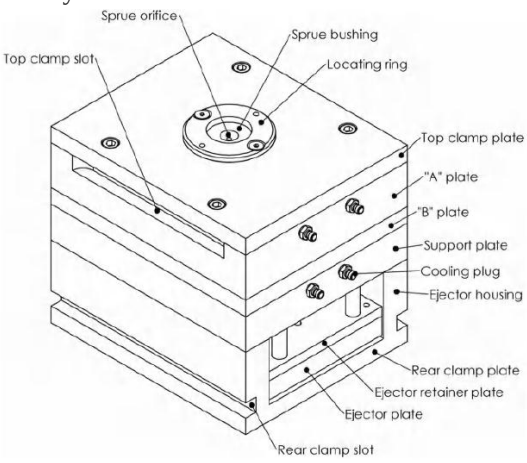

Fig. 1 Mold

A typical plastic injection mold is made in two halves: fixed and moving, which butt together during mold filling and move apart during part ejection. [2], [5] The construction of a typical injection mold is shown in Fig. 1[17]

II. LITERATURE REVIEW

An overview of the previous work was studied before proceeding with this project. To achieve a successful business in engineering industry it is crucial to plan the process. To deal with this problem estimation models which can predict the manufacturing time helps to great extent. [1] Most of the research work in this field is done on product complexity and cost estimation models. This model is based on the inhouse experts in the industries which can lead to underestimation, overestimation, impact future business decisions, economic loss.

Continuous requirement of new plastic products leads to new mold development which is a time-consuming activity. Vendors activities that consumes time are analyzing the product, designing the mold, estimating the manufacturing process, estimating the manufacturing time, estimating the project timeline, quotation, Negotiations, iterations in design. [3], [4]

Traditional approach of mold design and estimation is too slow to acquire new business. Artificial Neural Network (ANN) has potential challenges in the prediction, optimization, identification, classification and so in particularly in the field of manufacturing. [6]

From the reviewed papers following key issues were focused in applying ANN to practical problems,

1. Generation of training data for ANN
2. Neural network type selection
3. Network architecture design
4. Selection of learning algorithms for training
5. Selection of network parameters like number of layers, number of neurons, activation function and other parameters.
6. Monitoring training performance and validation

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III. METHODOLOGY

The objective is to develop an estimation model which helps product designer to improve the estimation of manufacturing time in the mold manufacturing.

A. *Manufacturing Technologies in Mold Making*

Injection molds are not mass produced but rather produced as single items. Normally every injection mold is manufactured only one time. The tool makers specializing in the field of mold technology must master or be able to handle all the manufacturing technologies which are

- Milling
  - 3-Axis Milling
  - 4 and 5-Axis Milling
  - 3+2 Axis Milling
  - Simultaneous 5-Axis milling
- EDM (Electrical Discharge Machining)
  - Sinker EDM
  - Wire EDM
- Grinding/Profile Grinding
- Drilling/Deep Hole Drilling
- Turning
- Laser Sintering
- Polishing

B. *Mold Design Using NX Mold*

Automation of mold design was carried out using NX Mold wizard. Fig. 2 shows the automation of mold design in NX mold wizard. [11]

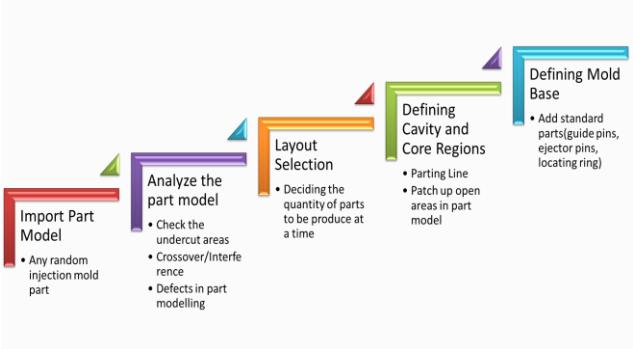

Fig. 2 Automation of Mold Design in NX Mold Wizard

Fig.3 shows the mold design for phone top cover using NX mold wizard along with layout design, core and cavity design.

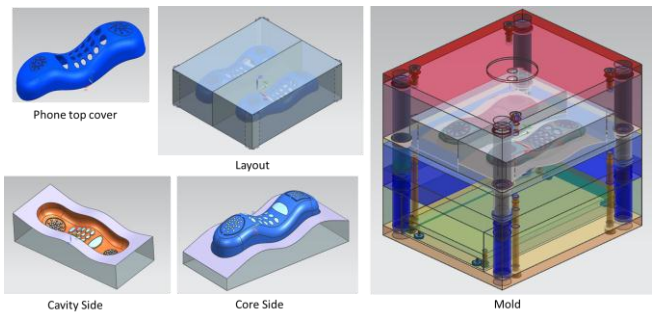

Fig.3 Mold for phone top cover using NX Mold Wizard

IV. COMPUTER AIDED MANUFACTURING

Feature Based Machining (FBM) technique was used to do Computer Aided Manufacturing (CAM) of mold components in NX CAM express. [8], [11]

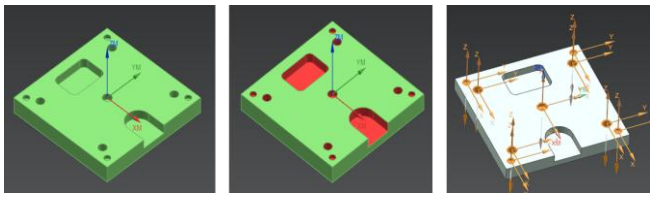

Fig. 4 Feature Recognition of Sample Plate for FBM

FBM makes intelligent decisions based on feature shape, size and Product and Manufacturing Information (PMI) such as dimensions tolerances and surface roughness. [12] These decisions include tool selection, operation and program definition. [14], [15]

As standard parts of mold like guide pins, ejector pins, bushing, screw, etc. are readily available so their CAM was not done. [13] CAM of customized components or the components of mold which vary according to the injection molded part was done. They include top clamp plate, upper mold plate, core, cavity, lower mold plate, ejector base plate, spacer, ejector retainer plate and bottom clamp plate. The report of CAM of each component was extracted from NX CAM express which gives manufacturing time has output.

V. ARTIFICIAL NEURAL NETWORK

Artificial Neural Network (ANN) is a computing system inspired from human brains. Such systems "learn" to perform tasks by considering examples, generally without being programmed with any task-specific rules. [1], [10]

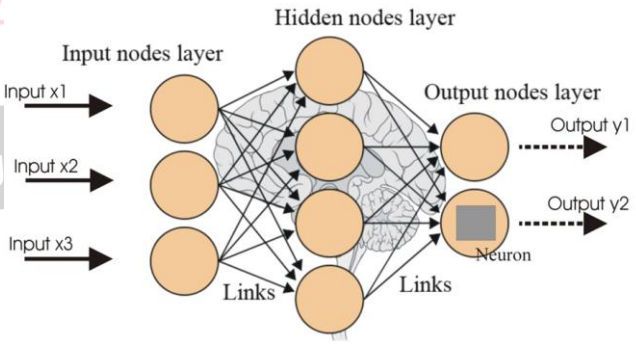

Fig. 5 Neural Network Layers

Training data for ANN was generated from CAM of twelve molds designed using NX mold wizard for the following injection molded parts

1. Phone Cover
2. Sharpener
3. Cardholder
4. Knob
5. On/Off Switch
6. Iphone Cover

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7. Logo
8. Air Vents
9. Wheel Cover
10. Handle
11. Side Mirror
12. Radiator Fan

Table 1 shows the parameters that were selected for ANN as input data. [1]

Some parameters are related to injection molded part geometry, tolerance, surface finish and some are related to mold. Complexity parameter was selected as judgement parameter. [1], [11], [16]

Verification parts were also decided to verify the ANN manufacturing time estimation model. They were

1. Gear Knob
2. Manifold
3. Dashboard
4. Headlamp
5. Bag Holder
6. Plug Cover

Both training as well as verification parts for ANN have small, medium and large parts by category. Injection molded parts from automotive category and general consumers category were selected.

Refer Appendix

Manufacturing time for verification parts was also calculated using NX CAM express so that the verification of ANN estimates can be done.

Table 1 ANN input parameters

Sr No	ANN input parameters	Unit	Coded Value
1	Length	mm	True Value
2	Width	mm	True Value
3	Height	mm	True Value
4	Average Wall Thickness	mm	True Value
5	Surface Area	mm^2	True Value
6	Volume	mm^3	True Value
7	Material		(-1) Semi Crystalline, (+1) Amorphous
8	No. of Cavities		True Value
9	Overall dimensional tolerance requirements of the part		Class 1(<0.01), Class 2(<0.05), Class 3(<0.1), Class 4(<0.5), Class 5(<1), Class 6(>1)
10	Complexity		(-1)Simple, (0)Moderate, (1)Hard
11	Undercut Areas		True Value
12	Mold Length	mm	True Value
13	Mold Width	mm	True Value
14	Mold Height	mm	True Value
15	Mold Core Thickness	mm	True Value
16	Guide Pin Hole Diameter	mm	True Value
17	Ejector Pin Hole Diameter	mm	True Value
18	Top Clamp Plate Thickness	mm	True Value
19	Bottom Clamp Plate Thickness	mm	True Value
20	Ejector Retainer Plate Thickness	mm	True Value
21	Screw Hole	mm	True Value

Fig. 6 shows the manufacturing time estimated by NX CAM express for various parts. On X axis is Manufacturing Time in minutes and on Y axis are the training parts.

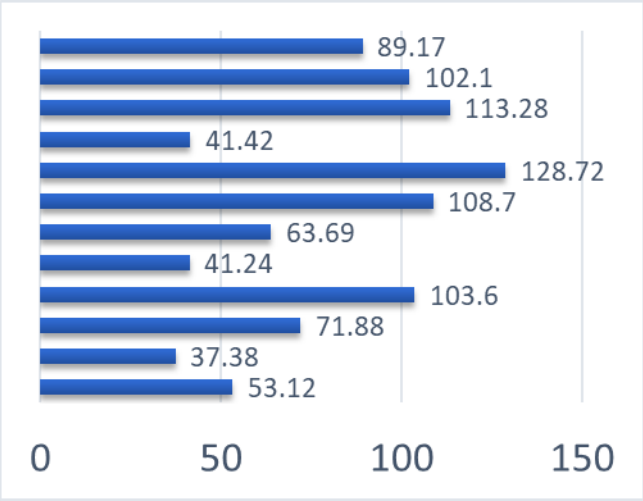

Fig. 6 Manufacturing time of various mold by CAM

VI. ANN MODELLING IN MATLAB

MATLAB nntool was used to do modelling of ANN. Fig. 7 shows the nntool in MATLAB [7]

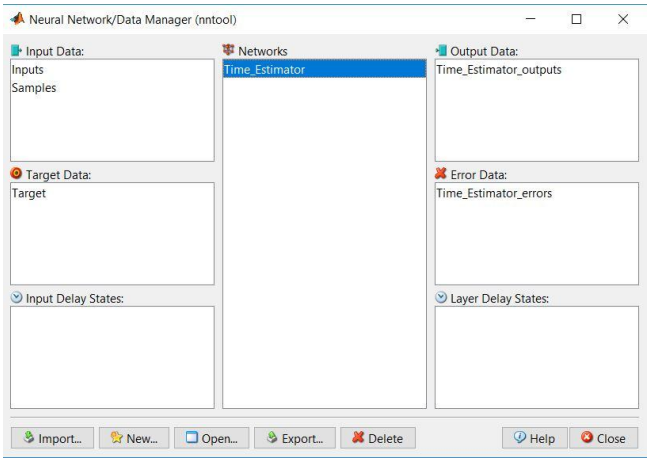

Fig. 8 nntool in MATLAB

Fig. 8 shows how the neural network defined. The number of layers were selected as 2, number of neurons as 12, activation function as logsig i.e. sigmoid function and the type of network was selected has feed-forward backprop which means data will flow in both directions forward and backward. [9]

Fig. 9 shows the neural network view, the number of layers and neurons.

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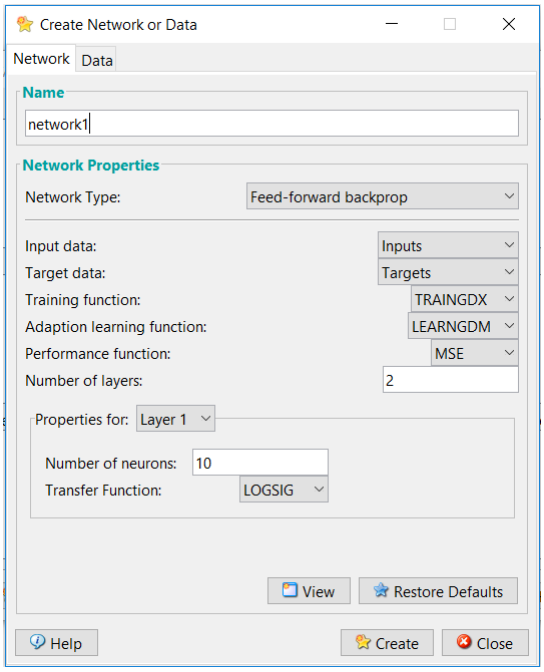

Fig.9 Defining Neural Network

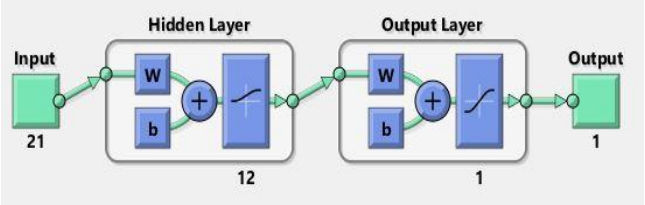

Fig. 10 Neural Network View

The training performance of the neural network can be viewed during training Fig. 9 shows the same.

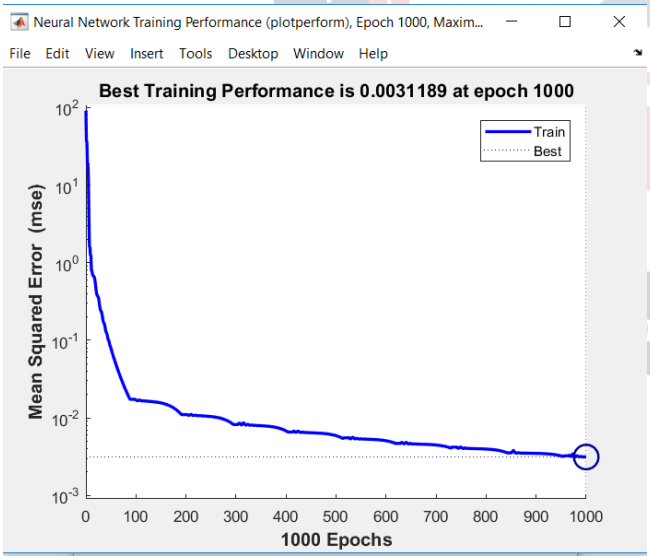

Fig. 11 Training Performance of Neural Network

The training performance shows that as the training progresses the Mean Squared Error (MSE) decreases and reaches Upto 10^{-2}, which implies that the training is going in right direction.

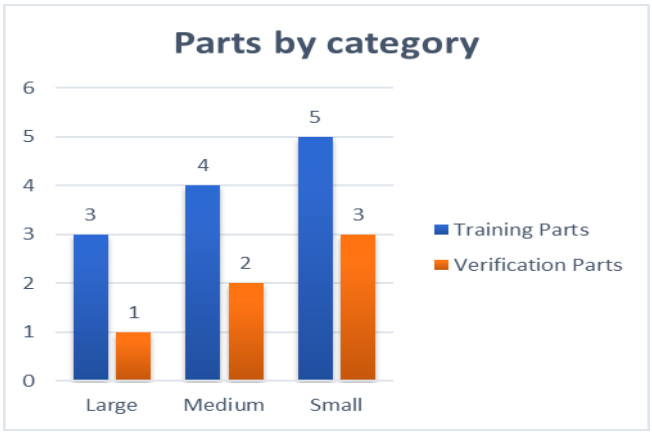

Fig. 12 Training and Verification Parts by Category

To ensure that the training is done for all category of parts like small, medium and large, graph of parts by category was plotted as shown in Fig. 12

VII. Flowchart Of the Estimation Model

Fig. 13 shows the flowchart of the estimation model, in which if the process follows Yes path it will take around 52 mins and if the process follows No path it will take around 77 mins.

The major time is consumed by mold design in NX mold wizard i.e. 20 mins which is still far less than conventional timing of mold design.

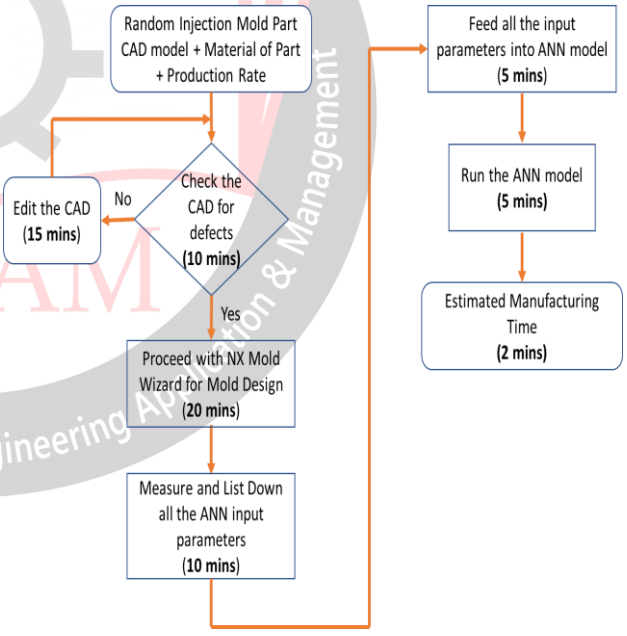

Fig.13 Flowchart of the estimation model

VIII. Results And Discussion

Table 2 ANN and CAM comparison

Part	Gear Knob	Manifold	Dashboard	Headlamp	Bag Holder	Plug Cover
ANN	39.469	128.0219	119.3949	124.6119	105.7562	39.0423
CAM	76.54	116.84	116.84	137.06	89.32	71.94

Table 2 shows the manufacturing time estimated by ANN estimation model and the verification values

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estimated from CAM.

Fig. 14 shows the graph of ANN and CAM estimation values.

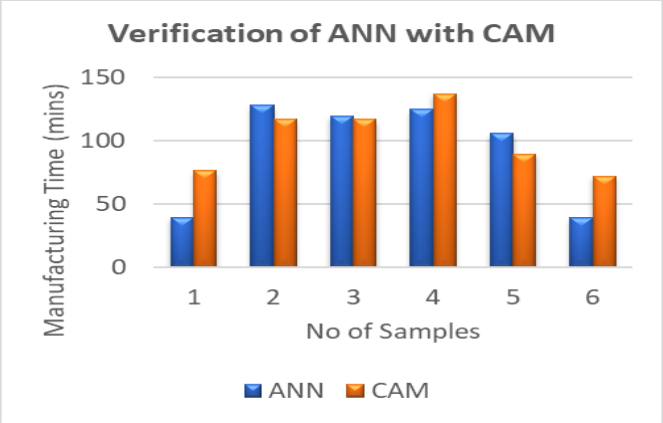


Fig. 14 Graph of ANN and CAM estimation values

From the graph we can see that the values of ANN model are closed to CAM estimation values. Only there is large difference between ANN and CAM values in case of part 1 i.e. gear knob and part 6 i.e. plug cover.

To find the difference in ANN and CAM the input parameters of ANN were analyzed.

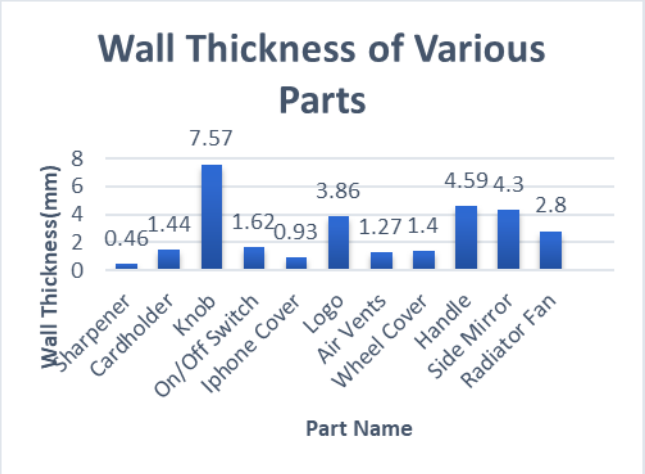


Fig. 15 Wall Thickness of Various Part

Fig.15 shows the wall thickness of various parts used in ANN training. Parts of thickness from 0.46mm to 7.57mm were used.

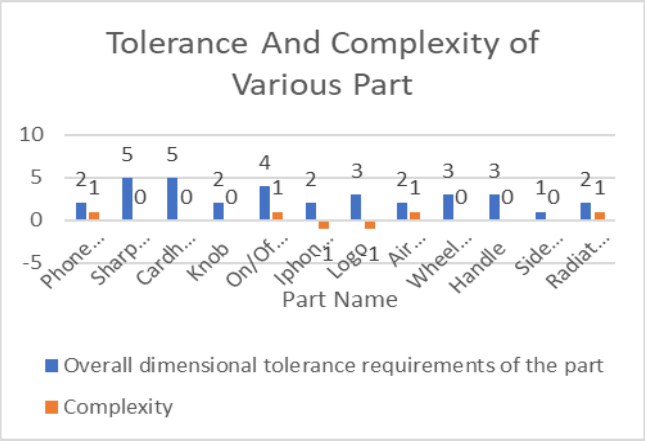


Fig. 16 Tolerance and Complexity of Various Part

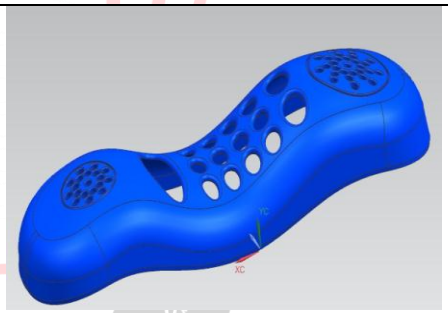
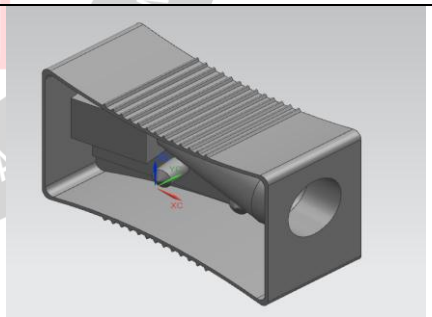
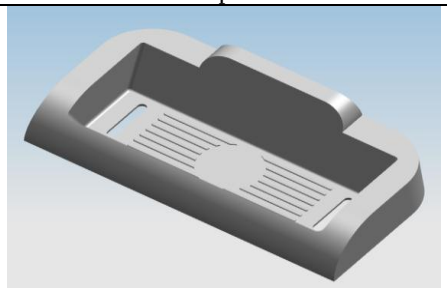
Fig. 16 shows the overall dimensional requirements of the part and complexity level. The tolerance was coded in the scale of Class 1 to Class 5 and complexity was coded in -1, 0, 1 where -1 means easy, 0 moderate and 1 hard.

IX. CONCLUSION

All category of injection molded parts was used for training from small to large parts. Injection molded parts from automotive industries, electronic and electrical industries were also used. Expert based decisions of manufacturing time estimation of injection mold for any random part was replaced by data driven ANN model. The ANN estimation model was verified with CAM and the correlation coefficient between them is 0.88. The trained artificial neural network "Time_Estimator" can be used for any random injection molded part-mold manufacturing time estimation. The network can be continuously upgraded as per the new data for more precise and accurate value of manufacturing time.

APPENDIX

Table 3 Training Parts

Sr No	Part
1	 Phone Cover
2	 Sharpener
3	 Cardholder

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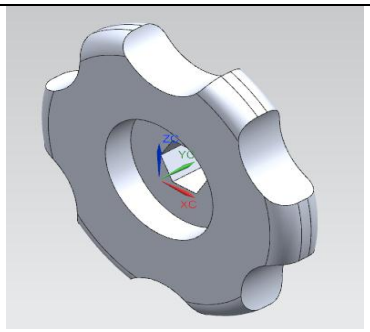
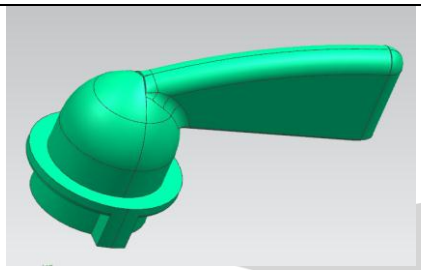
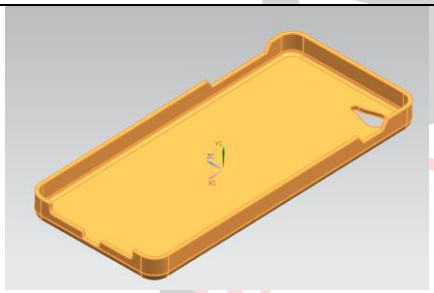
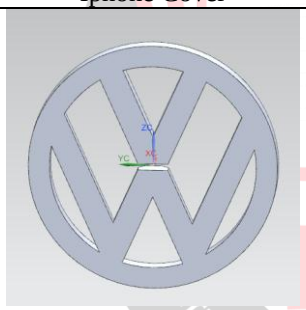
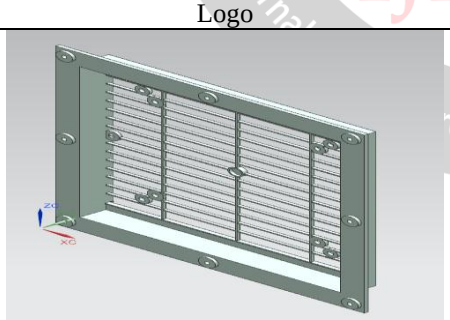
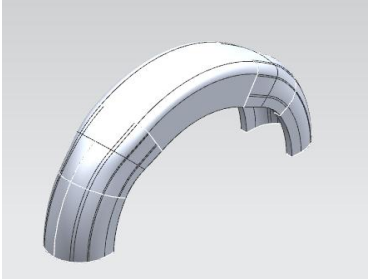
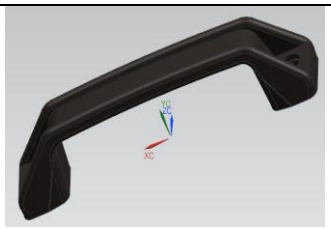
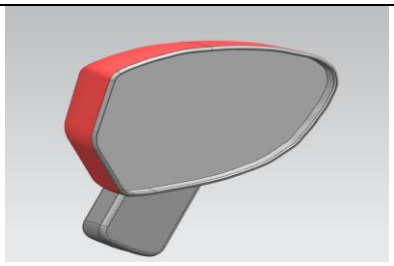
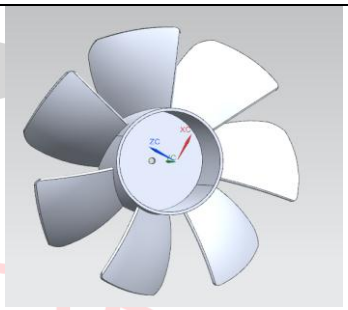
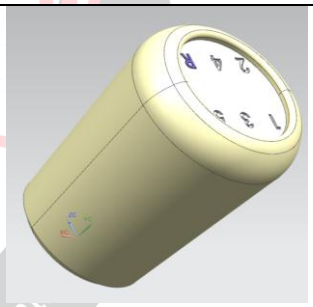
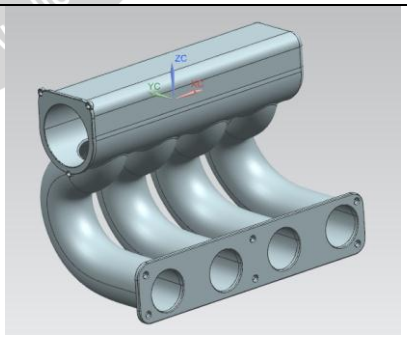
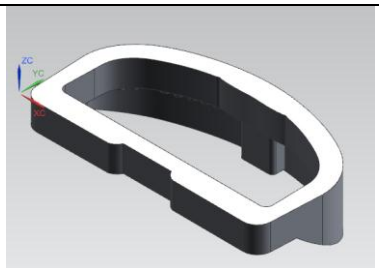
4	 Knob
5	 On/Off Switch
6	 Iphone Cover
7	 Logo
8	 Air Vents
9	 Wheel Cover
10	 Handle
11	 Side Mirror
12	 Radiator Fan

Table 4 Verification Parts

Sr No	Parts
1	 Gear Knob
2	 Manifold
3	 Dashboard

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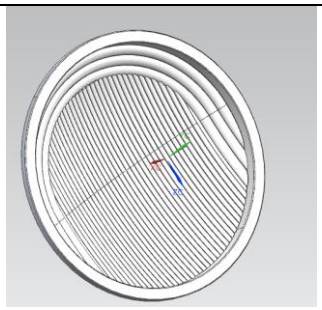
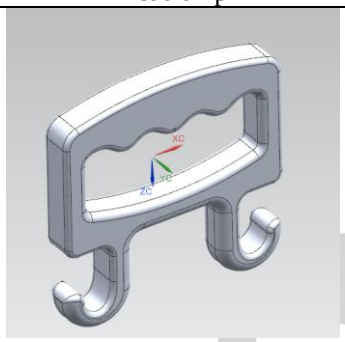
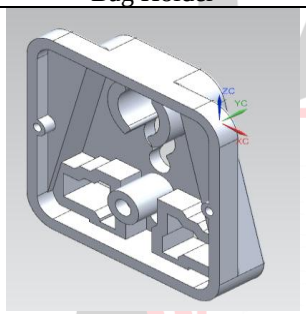
4	 Headlamp
5	 Bag Holder
6	 Plug Cover

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