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Heuristic Scales to Strayed Proneness (HSSP): Assessing the Strayed Proneness of Cross-Over OHE on Railway Tracks

By Ch Srihari Varma, T Rama Subba Reddy & Ch Sai Babu

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Keywords: overhead equipment (OHE), panto (pantograph), t/out (turn out), X-over (cross-over), ATD (automatic tensioning device), RE (regulated equipment), RDSO (research, designs and standards organization), SMI (standard maintenance instructions), TI (technical instructions), MI (maintenance instructions).

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Heuristic Scales to Strayed Proneness (HSSP): Assessing the Strayed Proneness of Cross-Over OHE on Railway Tracks

Ch Srihari Varma [α], T Rama Subba Reddy [σ] & Ch Sai Babu [ρ]

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I. Introduction

The 25KV, 1Φ, 50 Hz (Industrial Frequency) A.C. System was adopted for Indian Railways for high density traffic routes since 1957 collaboration with SNCF(French national Railways), since it was superior to other types of Electric Traction systems[1to 7].

The Traction system is divided into three major areas .i.e.

i) Power Supply Installations (PSI).
ii) Over Head Equipment (OHE) and
iii) Remote Control (RC).

All the above three are inter linked with one another and failure on any one of them may cause disruption in traffic (train movements) and causing loss of punctuality of trains.

The major important area of Railway Electric Traction is Over Head equipment (OHE).

The OHE consists of electrical conductors, huge number of insulators, various fittings, and numerous attachments to hold and maintain it in its place. A failure occurring in any one of the numerous parts of OHE could result in a breakdown causing heavy disruptions in railway traffic and causing indefinite delay of train services. So, there is a need of reliable and failure free OHE for smooth passage of Pantograph.

A scheduled maintenance of the OHE with meticulous inspection of every OHE installed parts is necessary to avoid any types of failure. The adjustments at the crossovers or near the overlaps spans have to be checked for any deviations from the specified standards leading to the pantograph getting entangled with the OHE. Also a periodic examination of the OHE parameters as per the design, healthiness of various components and its geometry is necessary to attain zero defects and to achieve high reliability. All OHE breakdowns .i.e. whether it is major or minor must be handled with equal urgency for preventing unduly disruptions and for renewal of the services.

Fig.1 : Electric Locomotive with panto raised condition.

The figure.1 shows the electric locomotive with pantograph in raised condition. The Pantograph is provided on loco roof to receive the required power from overhead contact wire to the electric locomotive. If the pantograph has free movement over the contact wire without any obstacles will ensures the locomotive works efficiently. However if broken fragment of the pantograph arise in the path of overhead wires or else broken overhead wires come in the path of the pantograph it will result in panto entanglement as shown in figure 4 and 5.

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Fig. 2 : Testing of turn out OHE with Tower Wagon

Fig. 3 : OHE Profile at Turn out Location

Fig. 4 : Panto entanglement at Turn out OHE.

Fig. 5 : Electric Locomotive with Broken Pantograph

The design of overhead equipment and pantograph ensures constant contact is maintained with contact wire by the pantograph with adequate pressure to obtain current.

Improper adjustment of stagger and heights of contact wire at turnout or cross - over results in pantograph entanglement with overhead wires while moving on the main line [4 & 5]. To avoid this, turnouts are to be adjusted such that the contact wire of secondary line remains 5 cm above the main line, OHE at obligatory structure and also the contact wires shall not be less than 30 cm up to 10m from obligatory structure. The emergency crossovers in between Up and Dn. main lines are also equipped with similar to turnouts. In case of panto entanglement the pantograph and OHE are both damaged and electric traction traffic is dislocated.

In this paper, one of the OHE defects[2] that can cause 43% among the OHE failures is presented. i.e. due to improper adjustment of 309 Nos Cross over and 1190 Nos. turn out OHEs of Secundrabad division of South Central Railway (Indian Railway).

II. RELATED WORK

Cross Over and Turn-out :

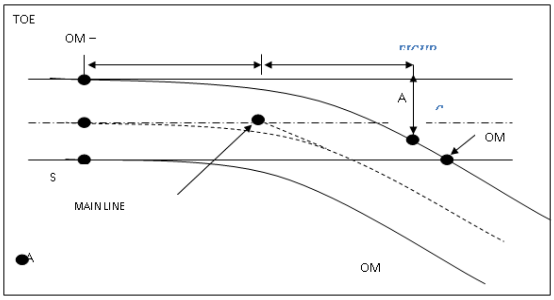

Fig. 6 : Cross-over & Turn out layout of Track

A cross over is a track which diverges from one track and converges to another track (Figure.6). This means a crossover will have two turnouts, which are connected by a cross over may be parallel or not, may be curved or may be having gradient in one track, or may be at different levels.

In the case of electrified tracks, at turnouts and crossings additional design parameters are obligatory to be considered for smooth take of pantograph from one OHE to another OHE (figure.3).

Since one cross over is constituted of two turnouts, each turnout parameters are to be designed as per the convergent or divergent point. The OHEs of the two mainline tracks are designed as per the normal principles of design irrespective of type of crossover. But the cross - over OHEs are to be designed in correlation with main line OHE[1& 7].

Another important parameter of turn out/ Cross-over OHE is that, the gradient of contact wires. Every cross over will have two elementary sections of the two tracks, separation of which is achieved by erection of section insulator. The erection of section insulator has got certain technical parameters to be followed during erection [5] which should not be infringed in any case by simply following the turnout heights of contact wire, otherwise results in panto entanglement.

The cross over OHE should be designed keeping the technical parameters for consideration

1) The heights of both mainline tracks OHE are to be adjusted such that there should be minimum allowed gradient of the crossover OHE.
2) Adjustment of crossover OHE should be done at a time in accordance with the as erected drawings supplied by the construction organization during erection and commissioning of OHE.

Any incorrect adjustments of stagger and height at turn out or cross over OHE causes entanglement of the pantograph with overhead wire during its movement on main line or else entanglement with main line during its movement on overhead line.

This problem may be overcome by making sure that height of the contact wire at turn-out or cross-over near obligatory locations is maintained 50 mm above the mainline contact wire and nearly 9m additional distance while pantograph moves on main line to make sure no contact is made with contact wire at turn out and cross over where the track separation is nearly 150 to 700mm.

Procedure for Adjustment of Turn Out and Cross Over:
A pre check that is necessary prior to the adjustment of Turn-out and Cross-over (figure.2) near any location is inspection of ATDs of main and loop lines for their free movement. The other steps in the procedure are,

1. Measure fitting of the obligatory mast from L/L & M/L tracks, track separation and perform turn-out adjustments at obligatory point according to SED.
2. Arrange 'G' Jumpers at a distance of 5.6m from obligatory mast at the points of cross-over and turn-out in the parallel run side direction.
3. Fix the contact wire at turn-out at a height 50mm above the M/L contact wire near obligatory mast located at the Cantilever.
4. Perform according to schedule, adjustments of the A&B droppers and tune distances of the A&B droppers from the obligatory mast for M/L and for turn out OHE.
5. Remove hogging on the M/L contact wire with adjustments of the length of 'B' and adjacent droppers to 10 m from the obligatory mast on M/L OHE contact wire in the direction of turn outside.
6. Perform height adjustments of L/L contact wire one mast previous to the obligatory mast considering M/L & L/L track level diff.
7. Execute in the direction of turn out side near 10 mts. distance adjustment of the height of loop line contact wire to min +30mm (with related adjustments of loop line B and the adjacent droppers) according to the height of main line contact wire.
8. Maintain at least 50mm diff. in the contact wire height at M/L & L/L OHE at obligatory mast.
9. Ensure panto does not come in contact with the contact wire of L/L cross over during operations of the tower wagon on M/L.
10. Running tower wagon at turn out track so that M/L contact wire achieves take in/take off panto pan of 650mm + /- 20cm from the center of panto of the tower wagon.
11. Maintain for a cross type turn out near obligatory a height diff. of +1.5 cms, at 5 mtrs and 10 mts distance from mast. In running the tower car on M/L ensure panto does not come into contact with contact wire at turn out and if necessary prevent contact by adjustments of A&B dropper.

III. HEURISTIC SCALE TO STRAYED PRONENESS (HSSP) OF CROSS-OVER OHE

a) Dataset Preprocessing

The OHE cross-over preventive maintenance log record contains 25 attributes with the values of type categorical. The 25thattribute is remark, which is descriptive, which is replaced by a Boolean value to represent the state of the respective record log. The dataset that used here in this experimental model is formed from the real time logs collected from the South Central Railway, Secundrabad division. The data set is the combination of records labeled as true and false. In order to balance the computational overhead, we aimed to select optimal attributes from the records labeled as true and also from the records labeled as false. Hence forth, initially we convert all alphanumeric values to numeric values and continuous values to be converted to categorical as follows.

Table 1: Description of dataset attributes:

ID	Description	Values
F1	Main line contact wire height on one side	in H meters (decimal fraction).
F2	Main line contact wire height on another side	in H meters (decimal fraction).
F3	T/Out Contact wire height on one side	in H+50meters (decimal fraction)
F4	T/Out Contact wire height on another side	in H+50meters (decimal fraction)
F5	Stagger of main line wire stagger on one side	in 200millimeters (decimal fraction)
F6	Stagger of main line wire stagger on another side	In200 millimeters (decimal fraction)
F7	Stagger of T/out wire stagger on one side	In300 millimeters (decimal fraction).
F8	Stagger of T/out wire stagger on another side	In300 millimeters (decimal fraction).
F9	sag of section insulator	in Zero mm
F10	Take-off from one side	In 650 to 720mm
F11	Take-off from other side	In650 to 720 mm
F12	Point take-off from one side	in 4meters (decimal fraction)
F13	Point take-off from other side	in 4meters (decimal fraction)
F14	stagger of section insulator	±100 mm
F15	Runner towards the centre of T/out.	In mm (1.65 minimum)
F16	runner away from the centre of T/out	In mm (1.45 minimum)
F17	condition of ATD of T/out & main Line	Free to move
F18	Hex tie rod of limiting device[6]	
F19	Setting distance of obligatory mast from one side.	In Metres (mi 3.0Mtrs)
F20	Setting distance of obligatory mast from other side side.	Same as above
F21	Track separation of obligatory mast from one side.	In mm (150 to 700mm)
F22	Track separation of obligatory mast from other side.	Same as above
F23	Distance of 'G'Jumper	In 5.6meters (decimal fraction).
F24	Length of 'G' jumper	In4 meters (decimal fraction).
F25	Label	true/false

- Let consider each attribute with alphanumeric values, then list all possible unique values and list them with an incremental index that begins at 1.
- Replace the values with their appropriate index.
- Let consider each attribute with continuous values, and then partition them into set of ranges with min and max values, such that the records distributed evenly through all these ranges.

b) *Optimal Attribute Selection*

- Partition the given network transactions as intruded (I) and normal (N)
- Find the hamming distance (see sec 3.3.1) between unique values of each attribute of I with the counter part of N
- Select the attributes having the hamming distance more than the given threshold hdt as set of optimal attributes I_a of size n , N_a of size m from I and N respectively

i. *Hamming Distance*

The value of Hamming Distance obtained here is to denote the difference between unique values of same attribute from records labeled true and false. This is one of the significant strategy to assess the difference between to elements in coding theory. This strategy is applied to identify the distance between the unique values observed for an attribute in record set labeled as true and labeled as false.

The hamming distance between given vectors $CX = \{cx_1, cx_2, ..., cx_n\}$ and $CY = \{cy_1, cy_2, ..., cy_m\}$ of size n and m respectively will be measured as follows:

```
Let $CZ \leftarrow \phi$ // is a vector of size 0
foreach $\{i \exists i = 1, 2, 3, ..... \max(n.m)\}$ Begin
    if $(\{cx_i \exists cx_i \in CX\} - \{cy_i \exists cy_i \in CY\}) \equiv 0$ then
        $CZ \leftarrow \{cx_i \exists cx_i \in CX\} - \{cy_i \exists cy_i \in CY\}$
    Else
        $CZ \leftarrow 1$
End
```

$$hd_{CX \leftrightarrow CY} = \sum_{j=1}^{|CZ|} CZ\{i\}$$

// $hd_{CX \leftrightarrow CY}$ is the hamming distance between CX and CY , $CZ\{i\}$ is the i^{th} element of the vector CZ and $|CZ|$ is the size of the vector CZ

c) *Heuristic Scales to Strayed Proneness*

Initially, we apply the Hamming Distance Analysis (see section 3.2) on processed dataset (see section 3.1). Then the records labeled true with selected optimal attribute values of are used for further process of finding Heuristic scale from strayed prone training records (records those labeled true) hs_{sr} (heuristic scale from strayed records) . Similarly the records labeled false with optimal attribute values are used to devise heuristic scale from normal records hs_{nr} of dataset.

Let set of strayed records $SR = \{sr_1, sr_2, sr_3, ...sr_n\}$ and set of normal records $NR = \{nr_1, nr_2, nr_3, ...nr_n\}$ formed by the values of optimal attributes selected (see section 3.2) from records labeled as true and records labeled as false respectively.

Prepare a sets $FS(SR) = \{a_1v_1, a_1v_2, ...a_1v_{m1}, a_2v_1, a_2v_2, ...a_2v_{m2}, ..., a_nv_1, a_nv_2, ...a_nv_{mn}\}$ and $FS(NR) = \{b_1v_1, b_1v_2, ...b_1v_{q1}, b_2v_1, b_2v_2, ...b_2v_{q2}, ..., b_pv_1, b_pv_2, ...b_pv_{qp}\}$ those contains all the unique values of all attributes of SR and NR respectively.

Here $\{a_1v_1, a_1v_2, ..., a_1v_{m1} \exists 0 < m1 <= |SR|\}, ...,$ $\{a_nv_1, a_nv_2, ..., a_nv_{mn} \exists 0 < mn <= |SR|\}$ presents the all possible unique values of optimal attributes $\{a_1 \in SR\}, ..., \{a_n \in SR\}$ respectively.

Similarly $\{b_1v_1, b_1v_2, ..., b_1v_{q1} \exists 0 < q1 <= |NR|\}, ...,$ $\{b_pv_1, a_pv_2, ..., a_pv_{qp} \exists 0 < qp <= |NR|\}$ represents the all possible unique values of the optimal attributes $\{b_1 \in NR\}, ...\{b_p \in NR\}$ respectively. Further the values of the set $FS(SR)$ and $FS(NR)$ are referred as respective features of SR and NR.

Further we build a weighted graph WG such that values of $FS(SR)$ as vertices and edges between these vertices under the constraints such as:

a) No edge is between two vertices, if those two are values of same attribute
b) An edge between two vertices that justifies the above condition is possible if those two vertices are appeared together in at least one given record.

Each edge weighted by the ratio of the given records contains the two vertices of the edge.

Further the closeness of the features $FS(SR)$ and records SR is assessed by using bipartite graph (see fig 7) build between those records and features.

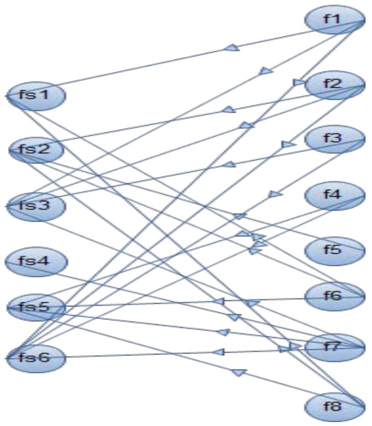

Fig. 7 : An example bipartite graph between features and records.

The edge between a feature $\{f_i \exists f_i \in FS(SR)\}$ and record $\{r_j \exists SR\}$ is the average of the edge weights between f_i and all other features in r_j found in weighted graph WG (see Eq1)

$$ew_{(r_i \leftrightarrow f_j)} = \frac{\sum_{k=1}^{k<|r_i|} \{ew_{f_k \leftrightarrow f_j} \forall f_k \in r_i \wedge k \neq j\}}{|r_i|} \quad .... \qquad \text{(Eq1)}$$

Then the feature weights from the bipartite graph are assessed as follows:

Initially a matrix that contains the edge weights of bipartite graph will be formed, such that each feature weight towards each record.

Further the link based ranking model [23] will be applied on bipartite graph (see fig 7) to evaluate the connected set. The confidence of each record r is proportionate to degree of all feature weights. Hence the influence of record r will be derived from these weights. Intuitively, a record with high confidence should contain many of the features. This approach is as follows.

Let matrix representation of records and features of set $FS(SR)$ as a matrix 'M'. The value represents the edge weight between record and features that calculated by using Eq1.

Find Feature support as matrix FC by summing up the columns of each row of matrix M' (which is transpose of matrix M) that represents edge weights between a feature of $FS(SR)$ and all records of SR.

The matrix multiplication between M and FC to obtain the record support.

$$RC = M \times FC$$

Then the confidence of each feature $\{f \exists f \in FS(SR)\}$ can be measured as follows

$$c(f) = \frac{\sum_{i=1}^{|SR|}\{RC(r_i)\exists f \subset r_i\}}{\sum_{i=1}^{|SR|} RC(r_i)}$$

$$hssp_{SR}(r_i) = 1 - \frac{\sum_{j=1}^{|FS(SR)|}\{c(f_j)\exists f_j \subset r_i\}}{ec(r_i)}$$

$ec(r_i)$ in above equation represents the edge count connected to record r_i

Then the heuristic scale of strayed proneness by strayed records $hssp_{SR}$ can be found as follows:

$$hssp_{SR} = \frac{\sum_{i=1}^{|SR|}\{hssp(r_i)\exists r_i \in SR\}}{|SR|}$$

Here, $|SR|$ indicates the records count

Further find the probable deviation of the " $hssp_{SR}$ " of records from SR as follows:

$$pd(hssp_{SR}) = \sqrt{\frac{\left(\sum_{i=1}^{|SR|}(\{hssp(r_i)\exists r_i \in SR\} - hssp_{SR})^2\right)}{(|SR|-1)}}$$

Here in the above equation $pd(hssp_{SR})$ represents the probable deviation of the strayed proneness of records of SR

The procedure that followed to assess the $hssp_{SR}$ (heuristic scale to strayed proneness) and $pd(hssp_{SR})$ (probable deviation) from records of the SR will be adopted to assess the heuristic scale to strayed proneness $hssp_{NR}$ and probable deviation $pd(hssp_{NR})$ of the records of NR.

Further these scales can be used to diagnose the scope of a given recordis Strayed Prone or normal, which is as follows:

i) Record r is said to be as Strayed Prone if

$$hssp_{SR}(r) > hssp_{SR} \,||$$
$$hssp_{NR}(r) < (hssp_{NR} - pd(hssp_{NR}))$$

ii) Record r is said to benormal if and only if

$$hssp_{NR}(r) > hssp_{NR} \,||$$
$$hssp_{SR}(r) < (hssp_{SR} - pd(hssp_{SR}))$$

IV. Experimental Study

The real time data (see sec 3.1) was used in experimental study. The overall data collected is the size of 303labeled records and each record contains 24 fields. Among these 213 records were used as training set to define the scale proposed. The remaining 90 records were used to test the scale defined in training phase. The empirical study delivered promising results. The statistics explored in table 2

Table 2 : Statistics of the experiment results

$hssp_{SR}$	7.11324
$pd(hssp_{SR})$	1.538036
$hssp_{NR}$	2.982372
$pd(hssp_{NR})$	0.623142

The attributes of the records selected as optimal under different hamming distances thresholds are defined in tables 5, 6 and 7 and the same is visualized in fig 8.

Table 3 : Hamming Distance Ratio of all 24 features of strayed records under normal records

Attribute ID	HD
1	0.082736
2	0.052226
3	0.075507
4	0.035821
5	0.027238

6	0.093627
7	0.07556
8	0.048156
9	0.057556
10	0.081826
11	0.068945
12	0.073293
13	0.039087
14	0.084389
15	0.089146
16	0.06504
17	0.048562
18	0.049054
19	0.020102
20	0.047748
21	0.071742
22	0.089284
23	0.056242
24	0.027358

Table 4 : Selected features of the strayed records with canonical correlation threshold >0.054 (mean of the hamming distance of all features)

Attribute ID	Hamming Distance Ratio
1	0.082736
3	0.075507
6	0.093627
7	0.07556
9	0.057556
10	0.081826
11	0.068945
12	0.073293
14	0.084389
15	0.089146
16	0.06504
21	0.071742
22	0.089284
23	0.056242

Table 5 : Selected features of the strayed records with Hamming Distance Threshold>0.025

Attribute ID	Hamming Distance Ratio
1	0.082736
2	0.052226
3	0.075507
4	0.035821

5	0.027238
6	0.093627
7	0.07556
8	0.048156
9	0.057556
10	0.081826
11	0.068945
12	0.073293
13	0.039087
14	0.084389
15	0.089146
16	0.06504
17	0.048562
18	0.049054
20	0.047748
21	0.071742
22	0.089284
23	0.056242
24	0.027358

Table 6 : Selected features of the strayed records with canonical correlation threshold >0.082

Attribute ID	Hamming Distance Ratio
1	0.082736
6	0.093627
14	0.084389
15	0.089146
22	0.089284

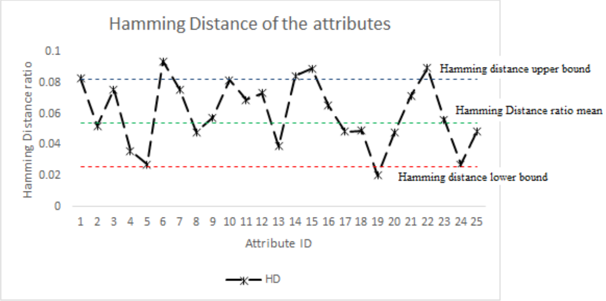

Fig. 8 : A line chart that representing the attributes scope under different hamming Distance thresholds

a) *Performance Analysis*

The results obtained for hamming distance threshold is greater than 0.082 are (i) false negatives:4 (strayed record claimed as normal),(ii) true negative are 17 (claimed records normal that are actually normal), true positives: 66,(iii) false positives: 3, and the prediction accuracy is 92.3%.

The experiments also conducted on the same data set under hamming distance ratio >0.052 and >0.025, the results are as follows:

Total records Tested 30% (90 records)(70 strayed records and 20 normal records) hamming distance ratio is greater than 0.052

Total number of records found false negative are 2(strayed record claimed as normal) and found to be true negative are 19 (claimed records normal that are actually normal)

Total number of records found to be true positives are 68 and false positives are1

As per these results, the accuracy of the proposed heuristic scale under hamming distance ratio of 0.052 is 96.5%.

The accuracy observed from the attributes selected under hamming distance ratio >0.25 also reflected the same performance accuracy, but delivered magnitude computational overhead that compared to the computational overhead observed under hamming distance ratio greater than 0.052

The observed time complexity is scalable since the completion time is incrementing with the same ratio against the increase in features count due to lower hamming distance ratio (see fig 9).

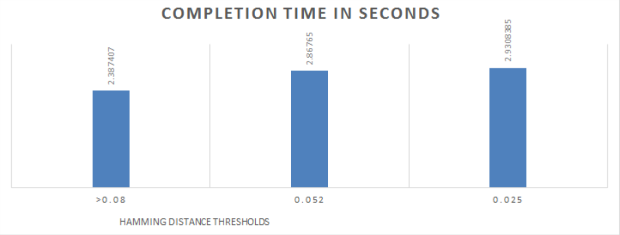

Fig. 9 : The completion time of defining HSSP under divergent hamming distance ratios

Hence it is obvious to conclude that hamming distance based optimized attribute selectionis significant to minimize the computational overhead of the proposal, which is done without loss of accuracy.

Table 6 : Results observed for statistical metrics under divergent hamming distance thresholds.

Hamming Distance Ratio	Precision	Recall	f-measure
>0.08	0.9565217	0.9850746	0.9705882
>0.052	0.9714285	0.9714285	0.9714285
>0.025	0.9715507	0.9714286	0.9714896

The statistical metrics [8], such as precision, recall, and F-measure were used along with prediction accuracy. The result obtained for these metrics under divergent hamming distance thresholds are explored in table 13 and visualized in fig 10

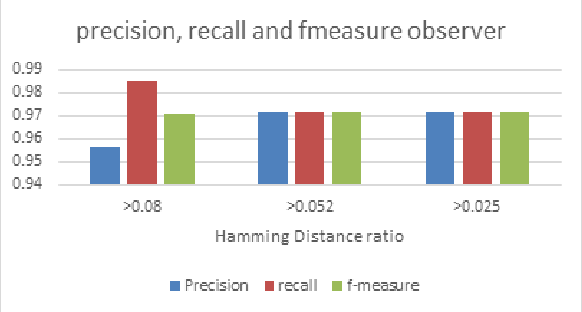

Fig. 10 : performance analysis of the prediction accuracy under divergent hamming distance thresholds given.

V. Conclusion

Heuristic scales to assess strayed proneness of the OHE provided on railway cross- over tracks has been proposed in this paper. The Hamming Distance Analysis of the recorded attributes is devised to obtain the optimal attributes, which is promising to simplify the process of defining Heuristic Scale to Strayed Proneness of the line cross-over's. The reinforcement relation between records and attribute values is analyzed to define the proposed heuristic scale. In order to this the proposed model is using a weighted graph that built by using optimal attribute values as vertices and their associativity scope as edge weight. The other significance of the proposed heuristic scale is that a given report of a line cross over is assessed by couple of heuristic scales called $hssp_{SR}$ and $hssp_{NR}$, which are built from the respective records of type strayed and normal. The experiments were done using real time data collected from Secundrabad division of South Central Railway zone. The exploration of the results concluding that the Hamming Distance Analysis is promising and significant to select optimal attributes of the records dataset. The heuristic scales proposed are observed to be robust and is with minimal process complexity and retains the maximal prediction accuracy. In future the evolutionary computational approach like GA, CUCKOO search can be devised.

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