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Temporal clustering of retroreflective marking

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ABSTRACT: The quality and reliability of road infrastructure and its equipment play a major role in road safety. This is especially true if we are interested by autonomous cars traffic able to read road marking. This kind of vehicles needs an accurate maintenance strategy to guarantee a road with marking perceptible for a human eye or an autonomous car. To simplify the study of a road and because a maintenance campaign is generally applied for a part of the road, a solution based on an Agglomerative Hierarchical Clustering to cluster all markings is chosen. In the case of no follow-up of the maintenance for markings, a maintenance detector will be introduced and described. Finally, with this classification, it is possible to extract all maintenance cycles and identify the different maintenance actions. This approach is a first step to analyze the useful life of marking with a Weibull analysis. Skip center line of the French National Road 4 is considered to illustrate the proposed approach.

Keyword : Agglomerative Hierarchical Clustering, retroreflection, marking, maintenance cycle

1 INTRODUCTION

The quality and reliability of road infrastructure and its equipment play a major role in road safety. This is especially true if we are interested by autonomous cars traffic. Currently, an autonomous vehicle is guided thanks to a GPS system. Unfortunately, this system isn't enough precise and not reliable (urban canyon, tunnel...). In order to complete the current system, an option consists in fitting the vehicle with a camera able to read markings. This solution needs an accurate maintenance strategy to guarantee a road with marking perceptible for a human eye or an autonomous car.

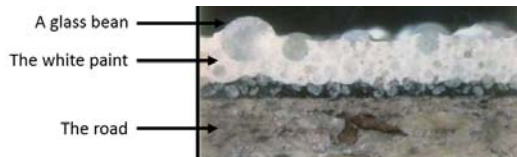


Figure 1. Sectional view of a white water-based paint retroreflective marking.

A retroreflective marking reflects the light from a vehicle on the direction of his driver. The figure 1 presents a white water-based marking. The paint is just laid on the road and glass beans are mixed to the paint. Their beans guarantee the retroreflexion property. In France, this kind of marking is mandatory for all roads located outside urban area (Instruction interministérielle sur la signalisation routière, 1988).

Markings are subjected to degradation over time, mainly due to the traffic, environmental conditions

and materials properties of marking and the road. Therefore markings lose paints and glass beans, be-

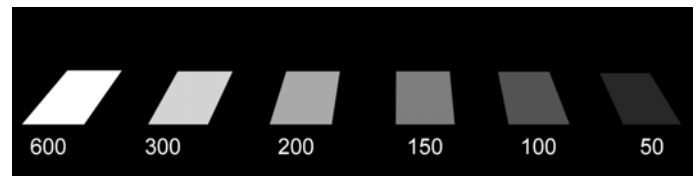


Figure 2. Representation of a white marking according to its retroreflexion level ($\text{mcd/m}^2/\text{lx}$)

comes grey... The retroreflectivity level of a marking is measured by millicandela by square meter and by luminance ($\text{mcd/m}^2/\text{lx}$). According to AFNOR rules (AFNOR, 2009), a minimum threshold of 150 $\text{mcd/m}^2/\text{lx}$ has to be respected by all constructors. The figure 2 represents a markings according to its retroreflexion level. With a high level of retroreflexion ($> 150 \text{ mcd/m}^2/\text{lx}$), the marking is white and seeable. But with a retroreflexion level less to 150 $\text{mcd/m}^2/\text{lx}$, it become grey and not enough seeable. The retroreflectivity level of a marking is a good indicator to analyze its degradation.

If a marking loses its retroreflectivity property then its replacement is the only possible maintenance action. Installment of markings in outside urban area is made by an adapted truck (Fig. 3a). For a water-based paint marking installation, experts could use the "sandwich" technique (Fig. 3b). The truck transport paints, glass beans and anti-skid products.

A first valve paints the road, a second puts glass beads on the marking and a last adds the anti-skid products. The quantity of each component depends to the constructor.



Figure 3. (a) A truck able to lay marking, (b) The "sandwich" lay technique.

The retroreflexion level of a marking is evaluated by a retroreflectometer. In this paper, an Ecodyn from Vectra is considered. This retroreflectometer is fitted to a car side and reliable to a laptop inside the car (Fig. 4a). This instrument measuring gives off a white light to markings and measuring the quantity of light retroreflected (Fig. 4b). Ecodyn measuring also thanks to some sensors the daytime and the nighttime contrast. The laptop creates automatically a data base and associate each measure to a point of reference thanks to an associated software (Fig. 4c).

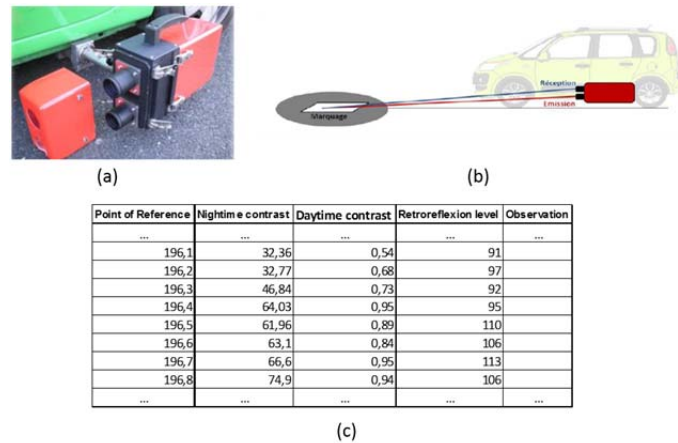


Figure 4. Presentation of an Ecodyn: (a) An Ecodyn fitting to a car, (b) The measuring process, (c) Example of a data base (Vectra France, 2017).

The current configuration could analyze the retroreflection level each 40 cm but gives only an average on 100 m. In fact, each measure represents an average of three or four markings. To simplify, a measure is analyzed like one marking.

To evaluate the economic impact of replacing a marking, a performance-based approach of the maintenance is chosen. Specifically in markings case, a preliminary work is: how each marking was

installed? What kind of marking was chosen? What is the current maintenance strategy? Are there some strategic area?

The major part of the literature supposes some conditions. For example: a test desk is considered (Bahar, et al., 2006) (Zhang & Wu, 2006), the study starts 6 months after the lay date (Karwa & Donnell, 2011), the kind of marking is known (Sarasua, et al., 2003) or the road is monthly inspected (Sathyanarayanan, et al., 2008). In addition, follow-up of the maintenance campaigns for markings and regular inspection campaigns are complete. In the reality, the follow-up may incomplete and markings could be inspected only once a year. As a result, incomplete data on the monitoring of marking retroreflectivity exists and installment dates of markings must be estimated.

Our approach is similar to (Migletz, et al., 2001) : the study is based on a specific road regularly inspected. To simplify the road and because a maintenance campaign is generally applied for a part of its, a solution based on an Agglomerative Hierarchical Clustering (Tufféry, 2011) to cluster all marking according to the geographic position and the retroreflection evolution is chosen. The study of the road is reduced to some cluster represented by an average profile. To estimate lay date of marking, a maintenance detector based on the previous clustering and accorded to AFNOR rules (AFNOR, 2009) is proposed.

Our hypothesis is that each cluster represents a specific part of the road. This part admits its own retroreflection evolution and past maintenance actions can be deduce.

Skip center line of the French National Road 4 (NR4) is considered to illustrate the proposed approach. This road joins Paris and Strasbourg. Since 2007, the part between Courgivaux and Perthes (~104 km) is managed by the DIR Est with two management teams (Direction Interdépartementale des Routes de l'Est, 2008). In order to evaluate the state of markings, one inspection a year is organized in collaboration with the CEREMA with an Ecodyn where each measure is located by a reference point. Unfortunately, it doesn't exist any follow-up of the maintenance campaigns for markings.

The following sections present the Agglomerative Hierarchical Clustering and the maintenance detector both applied on skip center line of the NR4.

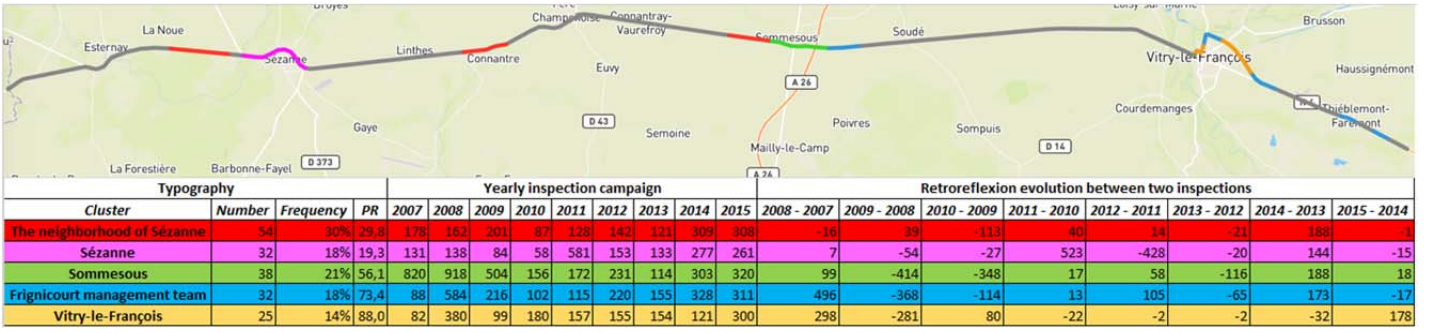


Figure 5. AHC of NR4 skip center lines and average profile of each cluster.

2 THE AGGLOMERATIVE HIERARCHICAL CLUSTERING

2.1 Definition and properties of the AHC

The Agglomerative Hierarchical Clustering (Tufféry, 2011) (AHC) consists to produce sequences of partitions of increasing heterogeneity between partition into n clusters where each object is isolated and partition into one cluster which includes all the objects. A marking is defined by its geographic Point of Reference (PR), inspections measures and retroreflexion evolution between two inspections. The general form of the AHC is the following:

1. Each marking is a cluster.
2. The distance between clusters are calculated.
3. The two closer clusters are merged into one.
4. Start again at step 2 until there is only one cluster, which contains all marking.

The second step introduces a distance between two clusters. In the case of two markings, the Euclidian distance d is considered. Else, the Ward distance (1) is chosen where X, Y are both clusters; x, y their average profiles; n_X, n_Y their numbers:

$$d_w(X, Y) = \frac{d(x, y)}{\frac{1}{n_X} + \frac{1}{n_Y}} \quad (1)$$

The choice of the number of cluster is based on the semi-partial R^2 criterion. This criterion calculates the loss of between-class inertial. This loss must be as small as possible.

The statistical software R could represent the clustering process and the semi-partial R^2 in a same dendrogram.

2.2 Application to the National Road 4

The DIR Est organizes in collaboration with the CEREMA the annual inspection campaign in late September. This period presents some advantages: main work sites are theoretically over, there isn't specific work like the maintenance of the flora and retroreflexion measures are registered before the first snowfalls. The retroflectometer used is an Eco-dyn from Vectra.

In this paper the monitoring between 2007 and 2015 of skip center line is restricted to markings inspected each time. 181 measures can be analyzed. It represents approximately 17% of the road. Each marking is defined by one point of reference, nine inspection measures and eight retroreflexion evolution between two inspections. In fact, a marking can be analyzed like a point in the space vector R^{18} .

The AHC proposes five clusters. According to the restricted data, Figure 5 shows all clusters directly on a map and presents all average profiles. A color code is chosen to represent the associate dendrogram (Fig 6). The semi-partial R^2 is small: 18%.

1. The first cluster (red) represents the neighborhood of Sézanne.
2. The second cluster (purple) represents the city of Sézanne.
3. The third cluster (green) represents the city of Sommesous.
4. The fourth cluster (blue) represents the Frignicourt maintenance team area.
5. The fifth cluster (orange) represents the city of Vitry-le-François.

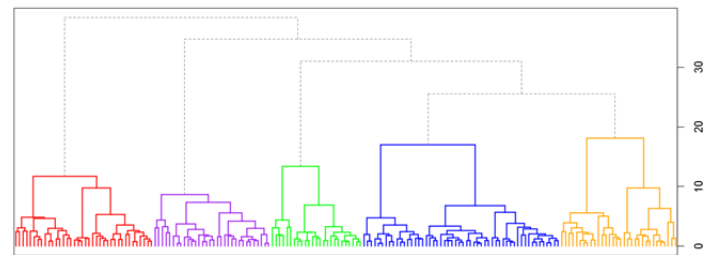


Figure 6. Dendrogram associated to the AHC of NR4 skip center lines.

Each cluster matches with a city area met by the road or one of two management teams. The first

three clusters represent the S  zanne management team area and the last clusters represent the Frignicourt management team area. From now on all clusters are named by its geographic area.

Cities of S  zanne, Sommesous and Vitry-le-Fran  ois present a specific road network. Figure 5 shows that S  zanne merges two departmental roads (D373a and D373b) in addition to the NR4, Sommesous is a highway (A26) exit and Vitry-le-Fran  ois merges two national road (NR44) and guides the traffic to Strasbourg, Paris or Northern France. These situations could create a local stronger traffic which could damage markings more quickly. A local maintenance strategy is required in this situation.

Admissible alternatives clustering propose three or four clusters. These versions considered one general maintenance strategy with one or two specific area (S  zanne and Sommesous) and a bigger semi-partial R². In the absence of maintenance historic, the maintenance detector and the current road manager strategy to the clustering is favored.

2.3 Mathematical formalism

An adapted mathematical formalism both to the clustering and the current studied is applied from now. Let suppose n markings and N_C clusters.

Each marking is defined by $i = 1, \dots, n$.

Clusters are noted by C_j where $j = 1, \dots, N_C$. The cardinal of a cluster C_j correspond to the number of marking classified in C_j and is noted by $\#C_j$. A marking took from C_j is noted m_k where $k = 1, \dots, \#C_j$.

According to the current literature, the Retroreflexion Level is noted RL . The retroreflexion level of a marking i at the inspection t is RL_t^i . The retroreflexion evolution between two inspections t and $t - 1$ is defined by (2).

$$\Delta RL_t^i = RL_t^i - RL_{t-1}^i \quad (2)$$

The retroreflexion level of a cluster C_j at the inspection t and the evolution between two inspections corresponding respectively to the average retroreflexion level (3) at the same inspection and the average evolution (4) in the same period.

$$RL_t^{C_j} = \frac{1}{\#C_j} \sum_{m_k \in C_j} RL_t^{m_k} \quad (3)$$

$$\Delta RL_t^{C_j} = \frac{1}{\#C_j} \sum_{m_k \in C_j} \Delta RL_t^{m_k} \quad (4)$$

$$e_t^{C_j} = \Delta RL_t^{C_j} - \sqrt{\frac{1}{\#C_j} \sum_{m_k \in C_j} (\Delta RL_t^{m_k} - \Delta RL_t^{C_j})^2} \quad (5)$$

A last indicator is the average lowest increasing for a cluster C_j at the inspection t (5). The right member is the standard error associated to $\Delta RL_t^{C_j}$.

3 THE MAINTENANCE DETECTOR

3.1 Construction of the detector

Two hypotheses are supposed. All inspections are realized after maintenance campaigns and indicated to managers which marking must be replaced during the next months and only one specific marking product (thermoplastic, water-based paint...) is laid.

A minimum threshold of 150 mcd/m²/lx for a no defective marking is chosen. For a marking i , four maintenance actions are identified.

1. A Full Maintenance (FM) consists to replace all markings.
2. A Partial Maintenance (PM) consists to replace only a part (~70-90%) of markings.
3. A punctual Maintenance (pM) consists to replace only a few marking (~1-30%).
4. Nothing (\emptyset) if no maintenance.

Let $a = \{FM, PM, pM, \emptyset\}$ is the set of maintenance action possible. The action into the marking i during the year t is noted a_t^i . Each year and for all cluster, the number of marking replaced is counted. The detector is based on two steps: the marking step and the clusters step.

The marking step is represented by figure 7.

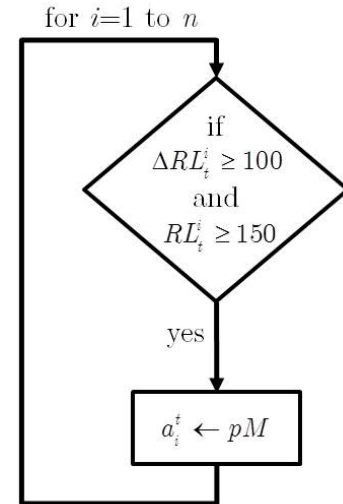


Figure 7. The markings step of the maintenance detector.

Let consider a given marking i at inspection t . If $\Delta RL_t^i > 100$ and $RL_t^i > 150$ then i is punctually maintained. An increasing (at least) 100 mcd/m²/lx could detect a marking replaced but also stressed during the period between the lay date and the first inspection.

The clusters step is represented by figure 8. Let consider a given marking cluster C_j at inspection t .

1. If $\Delta RL_t^{C_j} \geq 150$ then the cluster is fully maintained. This step detects all clear maintenance.
2. Else if $\Delta RL_t^{C_j} < 0$ or $RL_t^{C_j} < 150$ then the cluster isn't maintained. The step joins a maintenance campaign objectives: the cluster

have of a bigger retroreflexion level and isn't defective.

3. Else if $e_t^{C_j} > 0$ then the cluster is also fully maintained but markings are stressed.
4. Else C_j is subset to markings as $\Delta RL_t^{C_j} \geq e_t^{C_j}$. On the filtered cluster $C_j^{Filtered}$, if $\Delta RL_t^{C_j^{Filtered}} > 100$ and $RL_t^{C_j^{Filtered}} > 150$ then $C_j^{Filtered}$ is partially maintained.

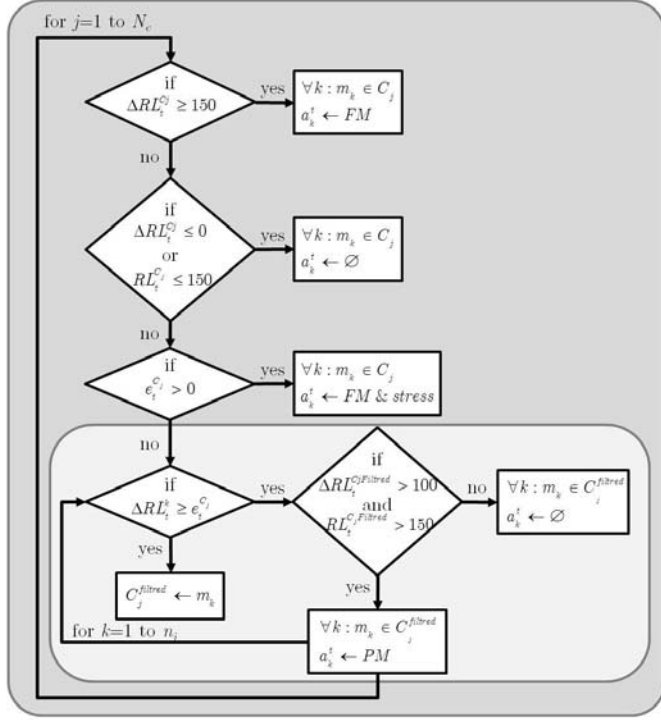


Figure 8. The clusters step of the maintenance detector.

3.2 Application to the National Road 4

According both to the AFNOR rules (AFNOR, 2009) and DIR Est directives (Direction Interdépartementale des Routes de l'Est, 2008), a minimum threshold of 150 mcd/m²/lx for a no defective marking is chosen. In 2008, the DIR Est chooses a water-based paint marking for the skip center line (Direction Interdépartementale des Routes de l'Est, 2008).

The table 1 indicates the maintenance action history of each clusters. Average profiles (Fig. 1) specified if a cluster was over maintained (a marking no defective replaced) or had an under maintained period (a defective marking not replaced). To simplify analysis, punctual maintenances are excluded.

1. The neighborhood of Sézanne is maintained in 2014. This cluster had an under maintained period between 2010 and 2013.
2. Sézanne is maintained in 2010 and 2014. This cluster had an under maintained period between 2007 and 2010.
3. Sommesous is maintained in 2008, 2012 and 2014. This cluster was over maintained in 2008.

4. The Frignicourt maintenance team is maintained in 2008, 2012 and 2014. This cluster had an under maintained period between 2010 and 2011.
5. Vitry-le-François is maintained in 2008 and 2015.

Cluster	Maintenance	2008	2009	2010	2011	2012	2013	2014	2015
The neighborhood of Sézanne	Full							100%	
	Stress								
	Partial								
	Punctual		31%		7%				4%
Sézanne	Nothing	100%	69%	100%	93%	100%	100%		96%
	Full				100%				
	Stress							100%	
	Partial								
Sommesous	Punctual								3%
	Nothing	100%	100%	100%		100%	100%		97%
	Full							100%	
	Stress					100%			
Frignicourt management team	Partial	79%							
	Punctual								8%
	Nothing	21%	100%	100%	100%		100%		92%
	Full	100%						100%	
Vitry-le-François	Stress					100%			
	Partial								
	Punctual								9%
	Nothing		100%	100%	100%		100%		91%
Total of marking replaced	Full	100%							100%
	Stress								
	Partial				84%				
	Punctual							8%	
	Nothing		100%	16%	100%	100%	92%	100%	
Total of marking replaced		48%	9%	12%	20%	39%	1%	86%	19%

Table 1. Estimate maintenance actions on the NR4 skip center lines between 2008 and 2015.

According both to restricted data and table 1, major maintenance campaigns took place in 2008 (48%) and 2014 (86%).

Even if Sézanne and its neighborhood are in the same management team area, they have two different histories. The first is regularly punctually maintained (31% in 2009, 7% in 2011 and 4% in 2015) and the second is fully maintained two times (2011 and 2014) and. Both benefit of a Full Maintenance in 2014. However, the second present a stressed situation.

Even if Sommesous and the Frignicourt maintenance team aren't in the same management team area, they have the same maintenance historic. However in 2008 Sommesous benefited of a partial over maintenance. This situation may be an extension of the maintenance campaign on the Frignicourt maintenance team cluster.

Our maintenance detector presents some limit.

1. A minimum of two inspections is necessary. In the NR4 case, maintenance actions in 2007 are not detectable.
2. Imperfect actions are not detectable. For example, if the "sandwich" technique (Fig 3b) is used to lay marking and the valve delivering glass beans is defective then "new" markings could be no retroreflective.

3. More regular inspections could detect more easily premature aging situations. The current literature shows that marking admits a fast decay period during the year after its installment (Sathyanarayanan, et al., 2008) (Karwa & Donnell, 2011) (Sarasua, et al., 2003). In addition to a strong traffic, this situation could explain why the first two clusters admit different maintenance in 2014.

In the case of no maintenance historic, our detector combined with clusters indicate main replacements. Thanks to estimate lay date, maintenance cycle can be identified. The detector shows that the AHC clusters in function to the strongest retroreflection values.

3.3 Validation of the detector

A marking maintenance cycle is defined by the evolution retroreflexion between its lay date and its replacement date. All cycle can be extract according to table 1. In the NR4 case, 14 cycles is identified.

Figure 9 shows the cycle between 2008 and 2011. It represents 62 markings located both Sommesous cluster and the Frignicourt management team cluster. According to table 1 in 2008, these clusters were respectively partially (79%) and fully maintained. Retroreflexion degradation evolves clearly on two step. The first step between 2008 and 2010 is a fast decay period: on average -400 mcd/m²/lx in 2009 and -200 mcd/m²/lx in 2010. The last step shows a stable retroreflection evolution: on average +15 mcd/m²/lx. This pattern is according to the current literature (Sathyanarayanan, et al., 2008) (Karwa & Donnell, 2011) (Sarasua, et al., 2003).

The detector is able to extract maintenance cycles and these cycles are according to the current literature. This result can be exploited for a next Weibull analysis.

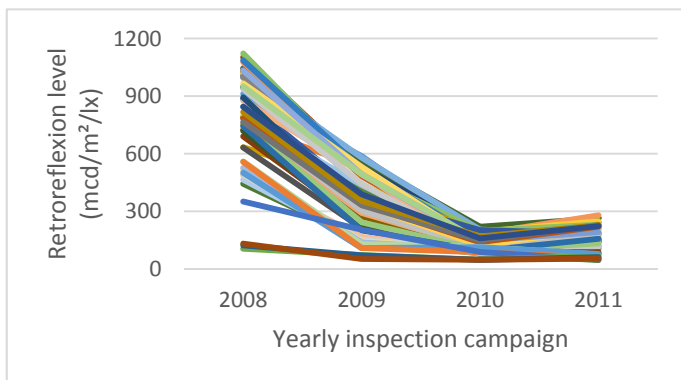


Figure 9. Maintenance cycle on the NR4 skip center lines between 2008 and 2011.

4 CONCLUSION

The current literature is based under some condition. For example: only a private cars trip is considered, the study starts six months after the lay date of markings or the road is monthly inspected. Our approach is more adequacy with the reality on the ground. The road is yearly inspected and there is no follow-up of the maintenance. To considerate a life analysis of marking, it's necessary to simplify the road to few strategic area and estimated main lay date of marking.

The AHC methodology is able to reduce the study to few clusters. In the case of no maintenance historic, our detector, combined with clusters, indicates main replacements. Thanks to estimate lay date, maintenance cycle can be identified. In the NR4 example, five clusters are identified. Each cluster shows strategic region and match with the current management. The maintenance detector identifies 19 replacement actions and 14 maintenance cycles. These cycles will be exploited for a next Weibull analysis.

Except the problem of no maintenance historic, the management of incomplete data isn't discuss. The AHC accepts incomplete data: it shows an extend version of current clusters. Unfortunately the detector cannot accept incomplete data because it need the evolution between two inspections. To complete data, (Sathyanarayanan, et al., 2008) purpose a linear interpolation approach. A proposition based on EM Algorithms (McLachlan & Krishnan, 2008) is investigated. Reasons are the retroreflection evolution isn't linear (Fig. 8) and the EM approach may evaluate missing data according to current data.

5 ACKNOWLEDGMENT

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