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# A Clustering-based Approach to Segment a Pavement Markings Line

Maxime Redondin<sup>a,\*</sup>, Laurent Bouillaut<sup>b,\*</sup>, and Dimitri Daucher<sup>c</sup>

<sup>a</sup>VEDECOM Institute, 23 bis Allée des Maronniers, mobiLAB, F-78000 Versailles, France.

<sup>b</sup>Université Paris-Est, Grettia (IFSTTAR), F-7755 Marne-la-vallée, France

<sup>c</sup>Université Paris-Est, Lepsis (IFSTTAR), F-7755 Marne-la-vallée, France

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## Abstract

The maintenance of road infrastructure is a classic social challenge, especially in the context of a decreasing maintenance budget and the advent of autonomous vehicle traffic. Road markings need an accurate replacement strategy to guarantee that the markings remain perceptible. The retroreflective luminance of markings is currently dynamically quantifiable only by using a retroreflectometer such as the Ecodyn from MLPC. The main objective of this research is to construct a performance-based approach for retroreflective marking replacement adapted to a given road network. This approach involves three main tasks: localize the strategic area based on past inspections, determine an adapted decay model for a given area, and evaluate the economic impact of replacing markings. This paper focuses on the first task. We apply the Agglomerative Hierarchical Clustering (AHC) method to a given dataset to obtain a suitable markings line segmentation. Markings whose retroreflective luminance exhibits similar evolution over time are interpreted to belong to a specific area of the road network. When no follow-up replacement has occurred, a replacement detector deduces the date at which markings were laid from the clusters. The broken center line of the French National Road 4 illustrates the proposed approach; the road is divided into 5 clusters and 34 lifecycles. A study of markings laid in 2008 and replaced in 2012 shows important variations in the decay of the retroreflective luminance as identified by the clustering approach. Even for a single road, an optimal replacement strategy for retroreflective road markings is necessary and is composed of several local maintenance strategies.

*Keywords:* pavement marking; retroreflection luminance; Agglomerative Hierarchical Clustering

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## 1. Introduction

The maintenance of one given road infrastructure is a classic social challenge, especially in the context of a decreasing maintenance budget and the advent of autonomous vehicle traffic. The first motivates the development of an original maintenance strategy according to a given budget over several years. The second will define different maximum degradation thresholds on the pavement, the surface signing, and road equipment. An autonomous vehicle employs several different sensors to analyse the road on which it travels. VEDECOM chooses a multi-agent approach based on a camera [1]. A reliable marking line is more than 95% detected with fewer than 2% of false alarms [1]. Applied on a degraded road infrastructure, 85% of the emergency line is correctly detected and the center line is not seen by the system [2]. A global preventive maintenance strategy based on given degradation thresholds represents a solution to solve these two issues. A preventive replacement strategy that is able to guarantee perceptible pavement markings is an adapted solution to optimize lane detection. A clear road surface marking is more important than a pavement in good condition for an autonomous vehicle guidance system. However, up to now most efforts have been focused on pavement quality only. For example, Wang et al [3] compares different stochastic processes to model road fatigue cracking and Zouch et al [4] proposes a condition-based imperfect maintenance of the wearing course.

An autonomous vehicle may inspect the road infrastructure and more specifically, inspect pavement markings during its journey. Nowadays, no example of a marking line regularly inspected by an autonomous vehicle is known. The current

\* Corresponding author.

E-mail address: [maxime.redondin@vedecom.fr](mailto:maxime.redondin@vedecom.fr)

method for evaluation of marking degradation is based on the retroreflection luminance (from vehicle headlights). This strictly positive integer variable is measured in millicandela per square meter and by lux ( $\text{mcd}/\text{m}^2/\text{lx}$ ). It is the only dynamically quantifiable measure and has become the only measure surveyed to evaluate marking degradation and its evaluation is subject to the strict conditions described in the NF EN 1436 rules [5].

Figure 1(a) illustrates the perception of a marking by nighttime according to their retroreflection luminance. For waterborne markings, this property is guaranteed by glass spheres mixed into the paint during application. A high level ( $> 150$ ) guarantees a visible white marking. Their main degradation over time is induced by traffic, environmental conditions, and the material properties of markings and pavements. Markings progressively lose paint and glass beans, causing their retroreflective luminance to decrease over time. These results in a below-threshold level ( $< 150$ ) and a visible grey object in the best case. When a marking's retroreflectivity has degraded sufficiently, replacement is the only possible maintenance action. European infrastructures require a minimum threshold of  $150 \text{ mcd}/\text{m}^2/\text{lx}$  for a new marking [5]. Marking retroreflectivity can be dynamically inspected using a retroreflectometer such as the Ecodyn from MLPC. A retroreflectometer is fitted to the side of a car and connected to a laptop inside the car (Figure 1(a)). A white light is shone on the markings (Figure 1(b): "Emission") and the quantity of the retro-reflected light is measured (Figure 1(b): "Reception"). Associated software automatically creates a database in which each measurement is associated with a reference location (a kilometric point for example). The standard configuration analyses the retroreflective luminance every 40cm but stores only the average over 100m.

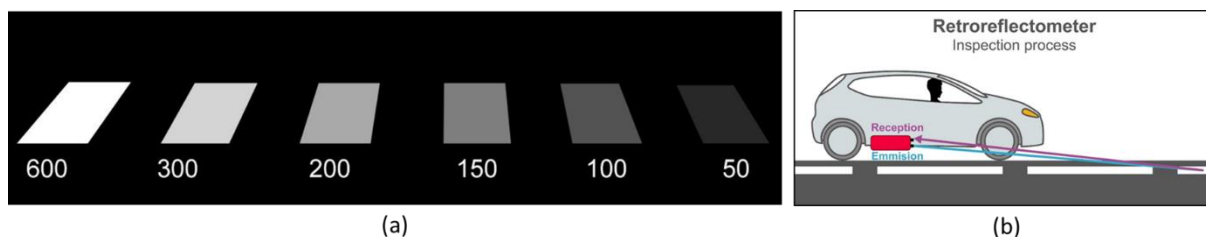


Figure 1. (a) Perception of a white marking according to its retroreflection luminance ( $\text{mcd}/\text{m}^2/\text{lx}$ ); (b) Inspection process

Several degradation models exist in the current literature that are mainly based on a regression model. Two common weaknesses are observed: they are difficult to apply directly to a given road network and they suppose an available follow-up of the replacement. A single line is also not systematically replaced in its entirety. For logistic and safety reasons, road managers maintain only specific areas at a time. A first task for a surface marking replacement strategy is to identify strategic areas. A follow-up of the replacement is necessary to identify all the lifecycles. The constitution of feedback data is therefore key to developing a degradation or a lifetime model and finally deducing an adapted preventive replacement strategy. Thus, the main objective of this study is to construct a clustering-based approach for retroreflective marking replacement that is adapted to a given lane. This approach involves three tasks: localize strategic areas based on a feedback database, determine an adaptive lifetime model for the given area, and evaluate the economic impact of marking replacement. This paper focuses on the first task and proposes a clustering approach to localize the strategic areas.

First, Section 2 presents a state of the art main degradation model for pavement retro-reflective markings. Such models provide a prediction of failure occurrences and a preventive replacement is engaged before this instant. Then, Section 3.1 proposes a segmentation of one given line using an Agglomerative Hierarchical Clustering (AHC) approach [6]. Markings with similar retroreflective luminance evolution over time are identified and each cluster is interpreted with respect to a specific area of the road network. Section 3.2 completes this approach with a replacement detector to estimate the date at which markings were laid. The detector searches for a median retroreflection luminance gain between two inspections. In Section 4, an illustration of this approach is proposed, using a part of the broken centerline of the French National Road 4 (NR4). The surface signing is inspected once a year, but replacement follow-up is not available. However, every replacement campaign for marking is done in March. This situation runs counter to the literature, which assumed monthly road network inspections and completed follow-ups of required replacement. The road is divided into 5 clusters with 34 lifecycles. The study of markings laid in March 2008 and replaced in March 2012 shows that even on the same line and under the same cycle, important variations in the degradation of retroreflection luminance occur. The proposed clustering approach can isolate each different degradation mode. Finally, this example shows that even for a single road, an optimal replacement strategy for retroreflective road markings consists of several local maintenance strategies.

## 2. State of the Art of Current Degradation Model of Retroreflective Marking

The two main research fields regarding pavement markings are its detection by visibility sensors and its degradation. Hillel

et al [7] presents research on lane detectors. The preferred sensor is a camera used with a clustering process able to extract markings from each image. The VEDECOM Institute proposed a multi-agent approach previously presented [1-2]. Independently: Xiao et al [8] and Lee et al [9] propose different options based on cameras. Kumar et al [10] proposes a solution based on a LIDAR and a cartographical approach is proposed by Hazelhoff et al [11]. A basic idea is to consider a lane detector as an inspection process. For example, Costello et al [12] proposed an inspection policy by camera and introduced five degradation levels. A stochastic maintenance strategy based on this model. However, this is a non-standard strategy and no example of a feedback database created by a lane detector is known. The current inspection process is based on a retroreflector and current degradation models evaluate the retroreflection luminance. This variable is explained by a regression method as a function of time, traffic, marking material, or lateral locations of markings. Such models provide a prediction of failure occurrences and a preventive replacement is engaged before this instant. A recent development is proposed by Owusu et al [13]. This paper presents the main degradation models currently used to evaluate retro-reflective markings.

The age of markings variables is present in all such models. It is also the only variable used on the exponential model proposed by Lu [14], linear models proposed by Scheuer et al [15], Taek et al [16], Sarasua et al [17] and Thamizharasan et al [18], and the inverted quadratic equation model proposed by Bahar et al [19]. Abboud and Bowman [20], Lindly and Wijesundera [1], and Lee et al. proposed independently the Vehicle Exposure (*VE*) variable defined as a weighted product of the Annual Average Daily Traffic (*AADT*) and the age of markings. Each one proposed a logarithmic model function of the *VE*. Road infrastructure characteristics such as the traffic or the locations of markings are also considered by Karwa and Donnell [21] or Sitzabee et al [22]. The first proposed a multi-layer perceptron. The second proposed a multilinear model optimized to thermoplastic markings and is a function of time, the initial retroreflection value, the *AADT*, the lateral locations of markings, and marking color. This model admits an alternative for waterborne markings and the number of snowplow transits is added by Mull and Sitzabee [23].

At least three papers bring into question a degradation model based on a regression technique. Ozelim and Turochy [24] recommend only models proposed by Sitzabee et al. [22] and Thamizharasan et al. [18]. Migletz et al. [25] and Kopf [26] show an important variation between models attributed to the road design, the marking material, the laying technique and the winter maintenance strategy. Some alternatives exist. Andrady [27] proposed an estimator of the useful lifetime of a retroreflective marking. Sathyanarayanan et al. [28] predicts the failure of given markings with a Weibull distribution. Asdrubali et al. [29] proposed the first known preventive replacement strategy for urban markings while respecting the NF EN 1436 rules [5]. Chimba et al [30] proposes a different degradation model based on a Markov chain.

Presented models are based on various assumptions. For example, Sitzabee et al [22] suggested an inspection after each replacement action, a follow-up of the replacement to estimate the age of markings, its material, one description of the road infrastructure, and an estimation of the *AADT*. Thus, this model is not adapted to a retroreflective line yearly inspected where its follow-up of the replacement is not available. Operationally, proposed degradation models must be applied directly on the whole line. This assumption doesn't consider an eventual local degradation process or different maintenance strategies on the same road infrastructure. For example, this paper presents a road infrastructure segmented into open country roads, suburban areas, bypass, and a short highway. The proposed clustering-based approach consists of first segmenting a line into different sections correlated to one specific local infrastructure. Each one is then interpreted as a replacement strategic area and admits its own evolution of the retroreflection luminance but also its own replacement strategy. This last property could then be used to define an estimation of the follow-up of the replacement in respect of the NF EN 1436 rules [5] and be based on the median evolution of the retroreflection luminance. The Agglomerative Hierarchical Clustering (AHC) method [6] is chosen to segment a given line.

### 3. Segmentation of a Markings Line by an AHC

In this paper, any markings line is composed of  $n > 0$  retroreflector measures defined by  $i = 1, \dots, n$ . Each one is localized by a Point of Reference (PR). To simplify, one measure is analyzed as one pavement marking localized by a PR. The retroreflection luminance of marking  $i$  at the inspection point  $t$  is denoted  $RL_t(i) \in N$ . The whole monitoring of markings according to inspections ( $T > 1$ ) realized is done by  $I(1)$ . One given marking  $i \in I$  is described only by its  $T > 1$  inspection data. The monitoring is not completed by a description of the road infrastructure for example. A graphical representation of  $I$  analyzes simultaneously the evolution of all markings from the first to the last inspection. A classic clustering approach, such as the AHC, identifies several clusters of markings that exhibit a similar retroreflection evolution over time.

$$I = \left\{ \frac{(RL_1(i); \dots, RL_T(i))}{i = 1, \dots, n} \right\} \quad (1)$$

### 3.1. Identification of Strategic Areas

The AHC interprets  $I$  as vectors in the vectorial space  $R^T$ . Applying AHC results in sequences of partitions with increasing heterogeneity between partitions, resulting in  $1 < N < n$  clusters in which data is first isolated and then partitioned into clusters that include all similar objects [6]. General steps of the clustering process are: 1) each data point is initially assumed to be a cluster, 2) the distances between clusters are calculated, 3) the two closest clusters are merged, and 4) repeat from Step 2 until only one cluster remains containing all data.

Steps 1) and 3) do not present any difficulties. Step 2) introduces a distance measurement between two clusters. The Ward distance (2) is selected, where  $d$  is the Euclidean distance. Here,  $I_x$  and  $I_y$  denote two clusters;  $\underline{I}_x$  and  $\underline{I}_y$  are their average profiles;  $\#I_x$  and  $\#I_y$  represent their numbers. Various choices for distance measurements exist, such as the minimum or median distance [6]. The Ward distance merges the two clusters that cause the smallest decrease in between-class inertia. In fact, the Ward distance is defined as the reduction in the loss of between-class inertia between two clusters. Step 4) introduces the need for a stopping criterion. The classic approach is to represent the whole clustering process by an associated dendrogram. As shown in figure 5, this graphic is specific to the AHC and indicates the Ward distance between two given clusters. A classic stopping criterion is cutting the dendrogram when a compromise between a few clusters and a large average inter-cluster distance is found. A double cut is proposed in this paper. The first cut is empirically optimized according to geographical and logistical considerations. Indeed, to accumulate many clusters is logistically difficult to maintain for safety reasons. To control the quality of the cut, clusters may be projected on a road map. Consider now  $N \geq 2$  clusters associated to the first cut denoted by  $I_1, \dots, I_N$ .

$$d_w(I_x; I_y) = \frac{d(I_x; I_y)}{\frac{1}{\#I_x} + \frac{1}{\#I_y}} \quad (2)$$

When no follow-up of the replacement has occurred, marking deposition dates must be estimated. A replacement detector is proposed and is based on three observations: the retroreflection luminance decreases over time, a sudden gain in retroreflection luminance signals that a replacement occurred and the AHC tends to identify important gains in retroreflection luminance. A second cut of the dendrogram looks for a partition of sub-clusters defined only by some replacement actions. Sub-clusters created by this second cut are denoted by  $I_1, \dots, I_M$  where  $M \geq N$ .

### 3.2. Identification of Replacement Action

The proposed detector compares systematically two inspections on every sub-cluster  $I_1, \dots, I_M$ . Consequently, it is unable to estimate replacement before the first inspection and estimated deposition dates are defined between two inspections. According to the NF EN 1436 [5], a minimum of 150 mcd/m<sup>2</sup>/lx is selected to represent a new marking. For a given cluster  $I_j \forall j = 1, \dots, M$ , five maintenance actions can be identified:

- A Full Replacement (*FR*) operation involves a replacement of all the markings.
- A Full Stressed Replacement (*FSR*) operation involves a replacement of all the markings but the initial or the sudden gain retroreflection luminance is relatively low. An over maintenance action is an example.
- A Partial Replacement (*PR*) operation consists of replacing only a part of the markings.
- A punctuated Replacement (*pR*) operation consists of replacing only a part of the sub-cluster.
- A maintenance operation of Nothing ( $\emptyset$ ) is applied when no maintenance operation was conducted.

Let  $A = \{FR, FSR, PR, pR, \emptyset\}$  be the set of possible replacement actions. The action detected for a marking  $i$  during the inspection  $t$  is denoted as  $A_t(i)$ . For all inspections and all clusters, the number of replaced markings is counted. As shown in Figure 2, the replacement detector is based on two steps: the marking step and the clusters step.

The marking step analyzes whether the marking was replaced between inspections  $t$  and  $t - 1$  (Figure 2(a)). The variation between inspections  $t$  and  $t - 1$  is done by  $\Delta RL_t$  (4). If  $\Delta RL_t(i) > 100$  and  $RL_t(i) > 150$  then the marking was replaced, and  $A_t(i) = pR$ . This step cannot determine whether this replacement action was isolated or is part of a wider

replacement campaign. An increasing value of (at least)  $100 \text{ mcd/m}^2/\text{lx}$  indicates a replace marking and can also be used to anticipate the degradation during the period between the deposition date and the inspection.

$$\Delta RL_t(i) = RL_t(i) - RL_{t-1}(i) \quad (3)$$

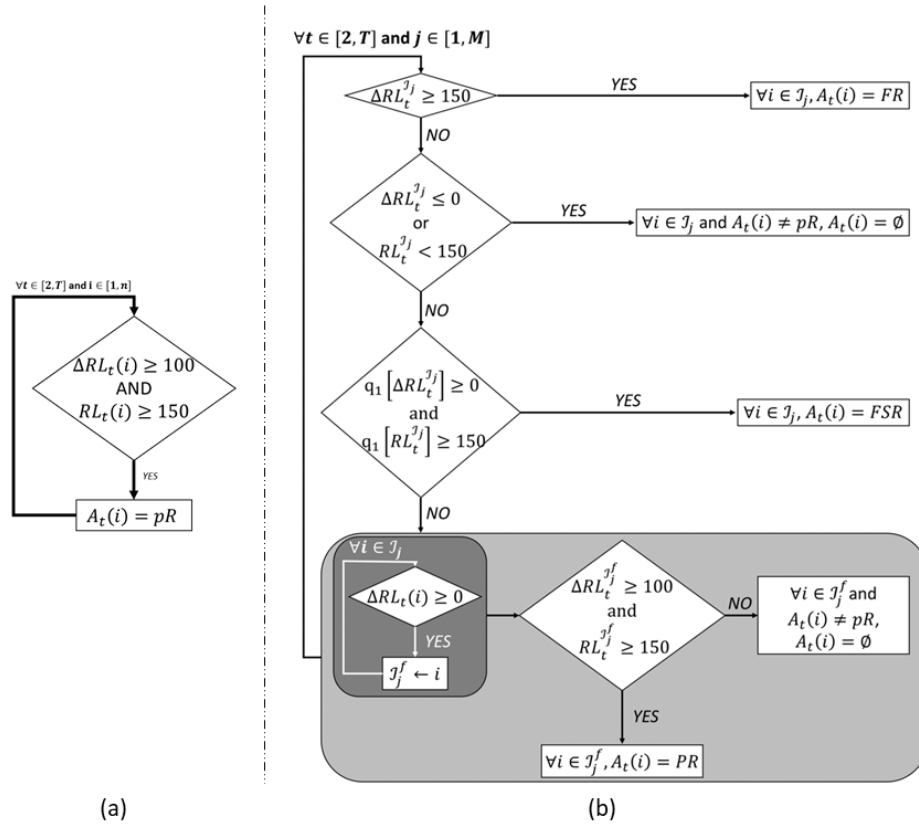


Figure 2. (a) The marking step to estimate marking deposition date; (b) The clustering step to estimate marking deposition date

Let us consider a given sub-cluster  $I_j$  at inspection  $t$ . The cluster step analyzes whether the cluster was partially or completely replaced between  $t$  and  $t - 1$  (Figure 2(b)). The process is split into four operations. Let us suppose  $\Delta RL_t^{I_j}$  to be the median retroreflection luminance variation between inspections  $t$  and  $t - 1$  observed on the sub-cluster  $I_j$ . If  $\Delta RL_t^{I_j} > 150$ , then the cluster was fully replaced:  $\forall i \in I_j, A_t(i) = FR$ . This step detects all clear replacements.

$$\Delta RL_t^{I_j} = \frac{1}{2} \left[ \Delta RL_t \left( \frac{\#I_j}{2} \right) + \Delta RL_t \left( \frac{\#I_j}{2} + 1 \right) \right] \quad (4)$$

Let us suppose  $RL_t^{I_j}$  to be the median retroreflection luminance at inspection  $t$  observed on the sub-cluster  $I_j$ . If  $\Delta RL_t^{I_j} < 0$  and  $RL_t^{I_j} < 150$ , then the cluster was not replaced:  $\forall i \in I_j$  and  $A_t(i) \neq pR, A_t(i) = \emptyset$ . This step meets replacement objectives: the cluster has a larger retroreflection luminance than is required by NF EN 1436 rules.

$$RL_t^{I_j} = \frac{1}{2} \left[ RL_t \left( \frac{\#I_j}{2} \right) + RL_t \left( \frac{\#I_j}{2} + 1 \right) \right] \quad (5)$$

Let us suppose  $q_1[\Delta RL_t^{I_j}]$  and  $q_1[RL_t^{I_j}]$  are the first quartile of the retroreflective luminance between  $t$  and  $t - 1$  and the first quartile of the retroreflective luminance at  $t$  on  $I_j$ . If  $q_1[\Delta RL_t^{I_j}] > 0$  and  $q_1[RL_t^{I_j}] > 150$ , then the cluster was fully replaced but the markings it contains are stressed:  $\forall i \in I_j, A_t(i) = FSR$ . By the first quartile definition, 75% of  $I_j$  involves a gain of retroreflection luminance and the markings meet the NF EN 1436 rules. According to the first two operations, this gain is between 0 and  $150 \text{ mcd/m}^2/\text{lx}$ . An over replacement action is included in this situation.

$$q_1 [\Delta RL_t^{I_j}] = \Delta RL_t \left( \frac{\#I_j}{4} \right) \quad (6)$$

$$q_1 [RL_t^{I_j}] = RL_t \left( \frac{\#I_j}{4} \right) \quad (7)$$

Let's suppose  $I_j^f(t)$  be the subset of  $I_j$  to the markings where  $\Delta RL_t > 0$ . This step constraints  $I_j$  to the markings that involve a gain in retroreflection luminance. If  $\Delta RL_t^{I_j^f(t)} \geq 100$  and  $RL_t^{I_j^f(t)} \geq 150$ , then  $\forall i \in I_j^f(t), A_t(i) = PR$ .

$$I_j^f(t) = \left\{ \frac{i \in I_j}{\Delta RL_t(i) \geq 0} \right\} \quad (8)$$

#### 4. Presentation of the French National Road 4 Broken Center Line

##### 4.1. Presentation of the French National Road 4

A defined part of the broken center line of the French National Road 4 (NR4) is considered to illustrate the proposed approach. The road is presented by Figure 3. The NR4 runs between Paris and Strasbourg. The direction heading toward Strasbourg is chosen. Since 2007, the section between Courgivaux and Vauclerc (~102km) has been managed by the DIR Est. Pavement markings are yearly inspected in late September in collaboration with CEREMA Est. The selected retroreflectometer is an Ecodyn from MLPC which annotates each measure with a Point of Reference (PR). The surface signing is replaced according to inspections and the current maintenance budget in March. However, there is no follow-up of these replacement campaigns for markings. The same marking product is supposed to be fit. In this paper, only the feedback data base created by the Ecodyn is considered. Between 2007 and 2016, 970 markings were monitored (95% of the considered NR4 section).



Figure 3. Presentation of the considered section of the French National Road 4

##### 4.2. Segmentation of the Broken Center Line

Figure 4 introduces a cartographic AHC representation of a NR4 broken center line over time. Each cluster is represented by its median profile and is named based on the nearest city or by a remarkable observation. The follow-up of replacement is not available. From now, both the median variation and the median retroreflection identify possible complete replacement. The last line represents the whole broken center line and presents some general observations. Except in 2012, 2015 and 2016, the median retroreflection luminance is always under  $150 \text{ mcd/m}^2/\text{lx}$ . Two possible important replacement campaigns are observed in 2012 and 2015:  $\Delta RL_{12} = 105$  and  $\Delta RL_{15} = 173$ . The longest decreasing period is observed between 2009 and 2011:  $\Delta RL_{09} + \Delta RL_{10} + \Delta RL_{11} = -82$ . The segmentation of the NR4 completes these observations.

(1) The cluster 1 corresponds to open country roads. It is the largest (43% of markings) and shows a weak median retroreflection luminance between 2007 and 2011:  $RL_{07}^1 = 103$ ,  $RL_{08}^1 = 118$ ,  $RL_{09}^1 = 103$ ,  $RL_{10}^1 = 53$ ,  $RL_{11}^1 = 55$ . Two possible complete replacements are observed in 2012 and 2015:  $\Delta RL_{12}^1 = 221$ ,  $\Delta RL_{15}^1 = 260$ .

(2) The cluster 2 is localized on different suburban areas. It is the second largest (35% of markings) and shows the weakest median retroreflection luminance over time:  $RL_{07}^2 = 96$ ,  $RL_{11}^2 = 51$ ,  $RL_{12}^2 = 120$ ,  $RL_{13}^2 = 101$ . One possible complete replacement is observed in 2015:  $\Delta RL_{15}^2 = 158$ .

(3) The cluster 3 is the bypass of Sézanne. This area was clearly replaced in 2011:  $\Delta RL_{11}^3 = 529$  and  $RL_{11}^3 = 577$ . A

strong degradation is also observed the next year:  $\Delta RL_{12}^3 = -406$ . A possible complete replacement is observed in 2014:  $\Delta RL_{14}^3 = 163$ .

(4) The cluster 4 is the bypass of Fère-Champenoise. This area shows a good median retroreflection luminance over the time:  $RL_{10}^4 = 160, RL_{13}^4 = 179, RL_{15}^4 = 365$ . Four possible complete replacements are observed in 2009, 2012, 2014 and 2015:  $\Delta RL_{09}^4 = 277, \Delta RL_{12}^4 = 75, \Delta RL_{14}^4 = 114$  and  $\Delta RL_{15}^4 = 72$ .

(5) The cluster 5 corresponds to a local free highway near the city of Sommesous. It is the smallest cluster (4% of markings) and shows the strongest median retroreflection luminance over the time:  $RL_{07}^5 = 826, RL_{08}^5 = 946, RL_{09}^5 = 510, RL_{14}^5 = 307$ . Two possible complete replacements are observed in 2008 and 2014:  $\Delta RL_{08}^5 = 141$  and  $\Delta RL_{14}^5 = 183$ . An important decrease is observed between 2008 and 2010:  $\Delta RL_{09}^5 + \Delta RL_{10}^5 = -760$ .

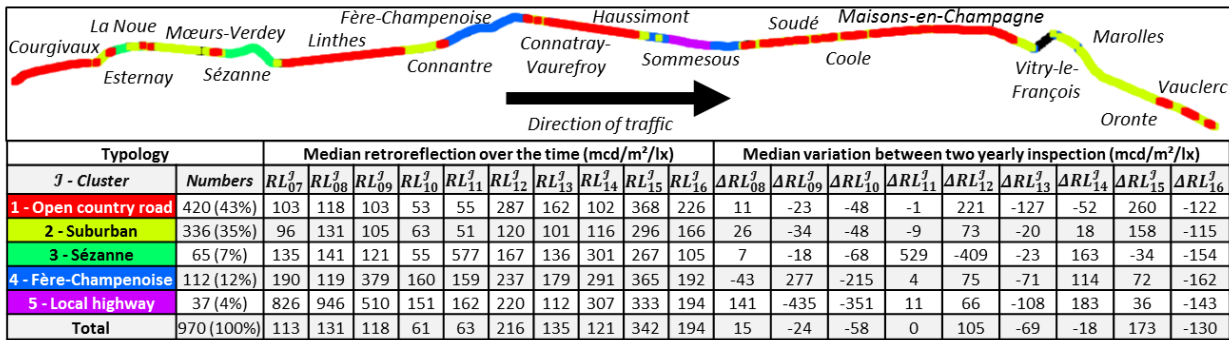


Figure 4. AHC representations of NR4 broken center line over time, showing the median profile of each cluster

The global analysis introduces two possible replacement campaigns in 2012 and 2015. This cartographical representation shows at least three additional pieces of information. First, the line is segmented into five clusters that are heterogeneous in size. Second, each cluster is correlated to some characteristic of the road infrastructure. Third, this segmentation identifies another possible replacement campaign. The two main examples are the clear complete replacement of Sézanne in 2011 and a possible replacement campaign on the three last clusters. However, this graphic does not represent the retroreflection monitoring and the clustering process remains to be verified.

Figure 5(a) shows the segmented monitoring of the broken center line between 2007 and 2016. Each cluster exhibits its own monitoring. For example, the local highway cluster shows a strong decrease between 2008 and 2010 (-760 in median), a small increase between 2013 and 2015 (+219 in median) and the retroreflection luminance remains high over time. Otherwise, the Fère-Champenoise and local highway clusters have been similar since 2010. Between 2007 and 2009, Fère-Champenoise presented clearly that two sub-clusters have been replaced in 2008 and 2009 respectively. Contrary to the previous analysis, different punctual replacements are identified in 2008 (cluster 2, 4 and 5), 2009 (cluster 4), and 2013 (cluster 1). Each inspection presents an important group which exhibits a low retroreflection luminance ( $< 150 \text{ mcd/m}^2/\text{lx}$ ). Finally, the segmented monitoring confirms and completes the cartographical representation. However, at least one cluster could be divided into two: Fère-Champenoise presents two different evolutions between 2007 and 2010. Otherwise, the part replaced in 2008 is localized around the local highway. This observation could justify a finer segmentation of the line.

Figure 5(b) shows the dendrogram associated with the clustering process segmenting into five clusters. Two alternatives are identified. A cut into three clusters would join on the one hand the local highway and Fère-Champenoise and on other hand Sézanne and suburban areas. The current segmented monitoring justifies the merge between the local highway and Fère-Champenoise because their retroreflection luminance is similar since 2010. However, three distinct evolutions are presented between 2007 and 2010. Otherwise, Sézanne is clearly isolated on the map representation and focuses on an important replacement campaign in 2011. The second alternative proposes a cut into six clusters. According to the dendrogram, this sixth cluster is a distanced part of the open country road clusters. However, it corresponds to a discontinuous section of only 1.5 km and is defined by only one important replacement in 2015.

Finally, the segmentation into five clusters seems to be a good compromise between limiting the number of clusters and producing clusters correlated to a specific characteristic of the road infrastructure. The replacement follow-up is not available and should thus be estimated.



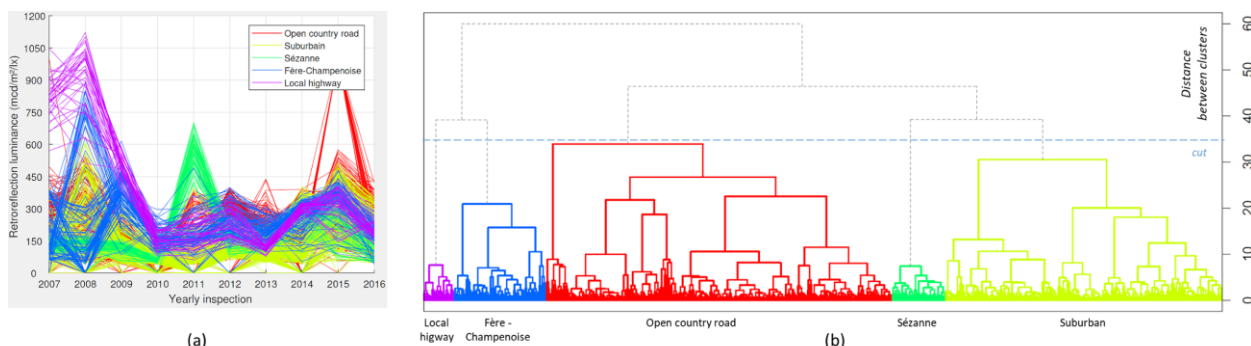


Figure 5. (a) Dendrogram associated with the AHC results of the NR4 broken center line; (b) Segmented monitoring between 2007 and 2016

### 4.3. Estimation of the Broken Center Line Replacement Follow-up

As presented in Figure 6, the second cut associated with the replacement detector is fixed at 15 clusters. This cut corresponds to a larger acceptable number of clusters. Contrary to the previous segmentation, sub-clusters are not necessarily correlated to a specific characteristic of the NR4: the sub-cluster 2 corresponds to the previous mentioned cluster 6 and is defined by a complete replacement in 2015, but the sub-cluster 10 corresponds to the bypass of Vitry-le-François. However, each one is associated with one cluster. Open country roads are composed of six sub-clusters: 1, 2, 3, 4, 5 and 6. Suburban areas are composed of four sub-clusters: 7, 8, 9 and 10. Sézanne is the sub-cluster 11. Fère-Champenoise is composed of three sub-clusters: 12, 13 and 14. The local highway cluster is the sub-cluster 15. Unsurprisingly, larger clusters are decomposed into several sub-clusters. On average, a given cluster is decomposed into 3 sub-clusters.

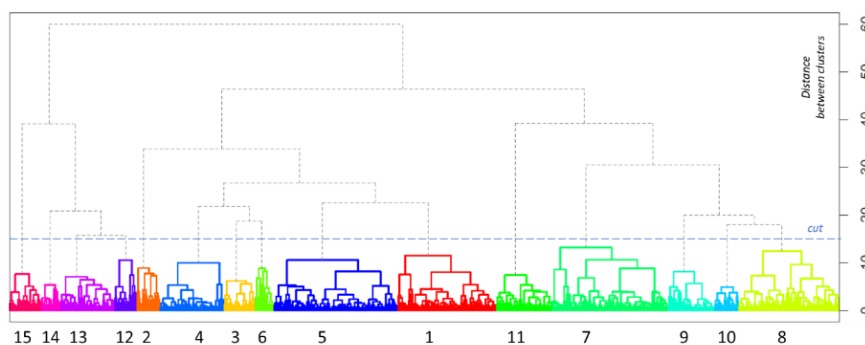


Figure 6. Dendrogram associated with the AHC results of the NR4 broken center line and associated median profile

Table 1 presents the follow-up of the replacement estimated using the replacement detector presented in Section 3.2. It indicates only the frequency of markings replaced. The last line is the whole broken center line. The two main replacement campaigns are estimated in 2012 (59%) and 2015 (77%). Few replacements are estimated in 2010 (3%), 2013 (3%) and 2015 (< 1%). Otherwise, the line benefits from targeted replacements. Each cluster is divided into its sub-clusters. For example, the open country road cluster is composed of 6 sub-clusters. Its sub-cluster 2 was partially replaced (56%) in 2008 and completely replaced in 2015. The whole cluster 1 was completely replaced in 2015 and no replacement was observed in 2010.

(1) Open country roads were completely replaced in 2015. Its sub-clusters exhibit on average 1.8 complete replacements since 2008. In 2012 (84%), its three larger sub-clusters 1, 4 and 5 were completely replaced.

(2) Suburban areas have never been completely replaced. In 2014 (41%), its larger sub-cluster 7 was completely replaced. The other sub-clusters are completely replaced next year (62%). On average, sub-clusters exhibit 1.25 complete replacements since 2008. Three complete replacements are observed on the sub-cluster 10 (bypass of Vitry-le-François).

(3) Sézanne was completely replaced in 2011 and 2014.

(4) Fère-Champenoise was completely replaced in 2012 and 2015. Sub-clusters show on average 3.6 complete replacements since 2008. Most of the observed complete replacements are stressed replacements. The 2015 replacement corresponds mainly to an over-maintenance action due to an opportunist action (77% of the whole line was replaced), in

combination with a complete replacement the previous year. Other stress replacements are mainly attributed to the important retroreflection luminance observed on the figure 9 combined with a slow degradation process.

(5) The local highway was completely replaced in 2008, 2012, 2014. The 2008 stress replacement corresponds to an over-replacement action.

Table 1. Estimated follow-up of the replacement of the NR4 broken center line

Cluster	Sub-cluster	2008	2009	2010	2011	2012	2013	2014	2015	2016
Open country road	1	13%	2%		3%	100%		2%	100%	1%
	2	56%	4%			37%	4%	4%	100%	
	3	11%	6%		100%	14%			100%	
	4		1%			100%		12%	100%	
	5	1%			3%	100%			100%	
	6				14%	5%	100%	5%	100%	
	Total	9%	1%		12%	84%	5%	3%	100%	< 1%
Suburban	7	29%	7%		10%	15%		100%	4%	1%
	8	6%	7%		6%	39%	1%	1%	100%	
	9	9%	11%		2%	2%		2%	100%	2%
	10	100%		100%		7%			100%	
	Total	23%	7%	8%	7%	21%	< 1%	41%	62%	1%
Sézanne					100%			100%	11%	
Fère - Champenoise	12	12%	100%	8%	23%	100%	8%		100%	
	13		100%			100%		100%	100%	
	14	100%			13%	100%		100%	100%	
	Total	24%	79%	2%	8%	100%	4%	77%	100%	
Local highway		100%				100%		100%	11%	
Global		18%	12%	3%	15%	59%	3%	35%	77%	< 1%

Legend: Partial Replacement Stress Replacement Complete Replacement

This summarized follow-up of the replacement shows that sub-clusters are built according to several complete replacement campaigns, occasionally supported by punctual replacement. For example, Sézanne was replaced twice since 2008. Larger clusters take advantage of targeted replacements. For example, the sub-cluster is included in the open country road cluster and is defined by only one important replacement in 2015. This follow-up provides additional information on the current maintenance strategy. For example, an important replacement campaign was done in 2015 (77%). This is the reason why no replacement was detected in 2016 (< 1%). A similar situation is presented in 2012 (59%) and 2013 (3%).

The replacement detector estimated 34 lifecycles between 2008 and 2016. Figure 7 presents the cycle of 92 markings deposited in May 2008 and replaced in May 2012. However, inspections are done once a year in September between 2008 and 2011. Retroreflective degradation clearly involves two steps. The first step, between 2008 and 2010, is a fast-decay period (median -625 mcd/m<sup>2</sup>/lx between 2008 and 2010). The second step shows a stable variation of +14 mcd/m<sup>2</sup>/lx. This pattern is in accordance with other reports in the literature from Sathyarayanan [27] or Sarazura [17]. This example clearly shows the differences in the degradation rate with respect to the clusters. The local highway clusters have the highest

retroreflection luminance. The open country road and suburban clusters have the lowest retroreflection luminance. However, the degradation rate is more stable in the suburban cluster. The Fère-Champenoise cluster has an intermediate retroreflection luminance between 2008 and 2010. Within the same lifecycle, four different degradation rates were identified by the AHC.

Finally, the NR4 broken center line example shows that clusters are localized to areas such as a city, a bypass, and so on. The current maintenance strategy could be estimated from the segmentation. For example, the local highway of Sommesous is isolated in the segmentation. The identification of several strategic areas shows the difficulty in directly applying a single degradation model for retroreflective markings, even on a given single road. Each cluster degrades at a specific rate, and more broadly, requires its own replacement strategy. A preventive replacement strategy adapted to this line should comprise several local replacement strategies. AHC applied across all inspections was able to define the entire strategic area.

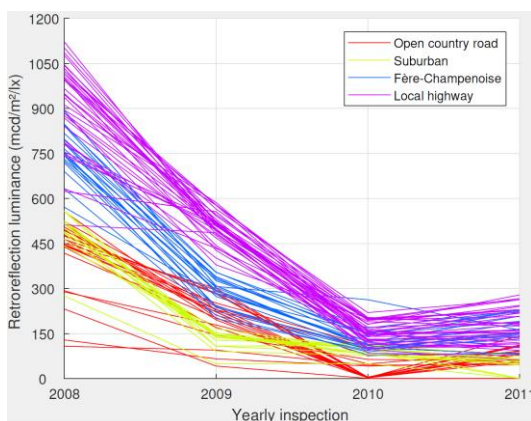


Figure 7. The 2008-2012 lifecycle segmented into the four presented clusters

## 5. Conclusion

Road infrastructure maintenance is a classic social challenge in the context of a decreasing maintenance budget. One important equipment to maintain are pavement markings which define traffic lanes. This is the reason why autonomous vehicle guidance systems include a lane detector. However, this option must be optimized by a preventive replacement strategy able to guarantee perceptible pavement markings and improve the quality and reliability of the road infrastructure. Currently, evaluation of degradation is based on retroreflection luminance. This measure evaluates the nighttime visibility and is dynamically quantifiable by a retroreflectometer such as the Ecodyn from MLPC.

The degradation is currently explained by a regression method as a function of time, traffic, or marking material. The associated preventive replacement strategy provides a prediction of failure occurrences. And finally, the replacement is engaged before this instant. However, these models present three main difficulties. First, the prediction quality shows an important variation from one model to another. Second, the follow-up of the replacement is known. Third, proposed degradation models must be applied directly on a whole line. However, a line is only observed by retroreflectometers and the follow-up of the replacement may not be available. Also, current assumptions do not consider an eventual local degradation process or different maintenance strategies on the same road infrastructure.

In this paper, the feedback database describes completely one given markings line and is generated by retroreflectometers. The monitoring over time of the retroreflection luminance is the first and only indicator to develop a preventive replacement strategy. A clustering approach simplifies the analysis. Each cluster presents one specific evolution over time, including each replacement action and be projected on a road map. Without additional information on the feedback database, the markings line is segmented into several maintenance strategic areas defined by both a specific evolution of the retroreflection luminance and a specific geographic position.

The Agglomerative Hierarchical Clustering (AHC) is chosen to segment the line. The clustering process is represented by a dendrogram which opens a discussion on the number of clusters to choose. This is the main reason why this approach was chosen. A double cut is proposed. The first cut segments a line into several sections correlated to one specific local infrastructure. The NR4 broken center line is segmented into five clusters. Each one is correlated to the road infrastructure: a bypass, a local highway or an open country road.

This paper introduces the situation where the follow-up of the maintenance is not available. A replacement detector is based on the following two observations. First, each cluster of the first segmentation exhibits its own evolution of the retroreflection luminance as well as its own maintenance strategy. Second, the retroreflection luminance decreases over time. The median gain of retroreflection luminance between two inspections per cluster is an accepted indicator to estimate the follow-up of the replacement. This detector is optimized by a second cut of the dendrogram. Sub-clusters deduced from it correspond to the larger acceptable number of clusters and are empirically defined by several gains of retroreflection between two inspections. The final replacement detector is also based on different decisions in respect of the NF EN 1436 rules.

The detector estimates 34 lifecycles between September 2008 and September 2016. The current replacement strategy is now known. The bypass of Sézanne has been completely replaced two times since 2008, for example. Complete life cycles are extracted from the estimated follow-up of the replacement and are similar to those presented in the literature. This paper presents the cycle of markings laid in March 2008 and replaced in March 2012. This monitoring is also segmented into four clusters. Each one exhibits its own degradation process. For example, the retroreflection luminance is strong on the local highway but the degradation process is very fast. This example shows that the segmentation of the whole line is also represented on a given life cycle.

Three limits are identified on the proposed approach. First, the segmentation is not perfect. For example, the section between Soudé and Maisons-en-Champagne is mainly classified as open country roads. However, small sections of 1 km classified in suburban clusters are included and correspond to some small cities such as Coole. In future work, the authors suggest completing the feedback database with a description of the road infrastructure and the complete surface signing. A first approach based on a factorial analysis presents a thinner segmentation based mainly on the traffic lane organization. These first encouraging results motivate an extending study including the French Government Open Data. Second, the clustering process is empirically stopped by a comparative study between the associated dendrogram and the representation on a road map. An automatic stopping criterion is advisable. Finally, the proposed replacement detector must be compared to a line regularly inspected with a complete follow-up of the replacement. Obviously, this work is necessary to estimate the prediction level of the detector. An additional interest is to optimize different steps, which are currently mainly influenced by the NF EN 1436 [5].

This paper proposed an original clustering-based approach to segment a pavement markings line. Even for a single road, an optimal preventive replacement strategy for retroreflective road markings is necessary and is composed of several local maintenance strategies. A line is now a segment on a different replacement strategic area. Each one could be associated with one degradation model based on a regression method. In future work, the reliability approach proposed by Sathyanarayanan et al [27] may be preferred because it represents an opportunity to develop a stochastic preventive maintenance strategy for road markings.

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