



# Likelihood ratio methods for forensic comparison of evaporated gasoline residues



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## ABSTRACT

In the investigation of arson, evidence connecting a suspect to the fire scene may be obtained by comparing the composition of ignitable liquid residues found at the crime scene to ignitable liquids found in possession of the suspect. Interpreting the result of such a comparison is hampered by processes at the crime scene that result in evaporation, matrix interference, and microbial degradation of the ignitable liquid.

Most commonly, gasoline is used as a fire accelerant in arson. In the current scientific literature on gasoline comparison, classification studies are reported for unevaporated and evaporated gasoline residues. In these studies the goal is to discriminate between samples of several sources of gasoline, based on a chemical analysis. While in classification studies the focus is on discrimination of gasolines, for forensic purposes a likelihood ratio approach is more relevant.

In this work, a first step is made towards the ultimate goal of obtaining numerical values for the strength of evidence for the inference of identity of source in gasoline comparisons. Three likelihood ratio methods are presented for the comparison of evaporated gasoline residues (up to 75% weight loss under laboratory conditions). Two methods based on distance functions and one multivariate method were developed. The performance of the three methods is characterized by rates of misleading evidence, an analysis of the calibration and an information theoretical analysis.

The three methods show strong improvement of discrimination as compared with a completely uninformative method. The two distance functions perform better than the multivariate method, in terms of discrimination and rates of misleading evidence.

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## 1. Introduction

At the Netherlands Forensic Institute, procedures for forensic gasoline (residue) comparison have developed from concluding in terms of the probability of same source or different source to concluding in terms of a likelihood ratio (LR) as a measure for the strength of evidence. A LR is assigned based on the comparison of a chromatographic analysis of a sample containing gasoline traces found at a crime scene and a sample containing gasoline traces found in connection to a suspect.

A likelihood ratio is defined as the ratio of the probability of the evidence given each of two competing hypotheses (for references in the forensic literature, see [1–7]). For example, it is reported that the observed similarities and differences in the chromatograms are much more probable when the gasolines share a common source than when they are from different sources (the sources will be defined later). In forensic science, as a matter of convention, the prosecution hypothesis

(here: same source) features in the numerator of the LR, while the defense hypothesis (here: different source) features in the denominator of the LR.

The present study is part of a research program to develop computer-based methods for forensic gasoline comparison resulting in a numerical LR. Computer-based methods may assist expert judgment by providing LRs that are transparent and have a clear empirical foundation in the training databases used. In this program a number of steps will need to be taken before the methods are suitable for application in forensic casework. In the current paper, evaporated gasoline residues are compared with other evaporated gasoline residues and unevaporated gasolines. Taking into account evaporation is a first step towards application in casework. In future steps the influence of the matrix and microbial degradation of gasoline residues found at crime scenes [8] will need to be taken into account.

### 1.1. The likelihood ratio framework for evidence evaluation

Presenting the strength of the evidence as a likelihood ratio is in concordance with the role of an expert witness in court, and leaves room for the other actors (judge, jury and other witnesses) to make their

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contributions. The general framework for application of a LR revolves around Bayes' theorem. When applied in a forensic setting, it dictates a connection between the odds of the two competing hypotheses (the prosecution and the defense hypothesis) prior and posterior to the taking into account of new evidence, and the strength of that new evidence as given by a LR. The odds of the hypotheses (the domain of the trier of fact) are dependent on all evidence and information, while the expert only has relevant information about the evidence within his field of expertise. An expert witness contributes to a trial by providing information about the probability of the evidence in the expert's domain (i.e. (dis)similarities in chromatograms for a gasoline comparison) under the two hypotheses. The ratio of these two probabilities is the likelihood ratio. The LR has values between 0 and infinity. Values smaller than 1 support the defense hypothesis ( $H_d$ ), and values larger than 1 support the prosecution hypothesis ( $H_p$ ) [1–7,9]. A value of 1 represents neutral evidence. Larger LRs give stronger support for  $H_p$  and LRs closer to zero give stronger support for  $H_d$ .

A LR approach is new to the field of gasoline comparison. Previous studies of evaporated gasoline residue comparison approach the problem as a classification problem. In these studies, samples of several sources of gasoline are prepared and it is studied whether numerical techniques can group gasolines from the same source. There is an important difference between a classification approach and a LR approach. Classification methods make categorical decisions based on the comparison only, while a LR provides the evidential value of the comparison result. The latter allows for logical combination with other evidence and information, and thus allows the trier of fact to decide based on all information available, while the former does not.

### 1.2. Comparison of evaporated gasoline residues

Even though the usefulness of classification studies for forensic purposes is limited, they do provide relevant information on which features of the chromatogram to use for a LR approach. We will therefore briefly describe a number of classification studies.

Some early work has been done on discriminating gasolines from different sources by fluorescence spectroscopy [10,11], but for most of these approaches the chemical composition is identified by gas chromatography (GC) [12–17]. This is done for a number of gasoline samples for which the amount of evaporation is varied under laboratory conditions. A first approach, pioneered by Mann [14,15] was based on analyzing chromatographic peak area ratios of volatile compounds. The use of volatile compounds limited the method to gasolines that were no more than 50% evaporated. This method was extended by Barnes et al. [12] to the qualitative comparison of a selection of peak area ratios including peaks at longer retention times and samples up to 75% evaporation. Peak area ratios (4 to 6 depending on the amount of evaporation under consideration) were selected based on minimal variation within a gasoline sample for varying amount of evaporation, and good discrimination between gasoline samples.

A second approach combines GC with statistical methods in order to reduce the dimensionality of the chromatogram data. In this approach the data is described by fewer variables than peaks in the chromatogram, while capturing a considerable amount of variance in the data. Sandercock & du Pasquier [17] used principal component analysis and linear discriminant analysis to discriminate samples up to 90% evaporation. They used the  $C_0$  to  $C_2$  naphthalene composition (11 late-eluting peaks in the chromatogram) as input for statistical analysis. In their study, 35 samples of gasoline (each evaporated to 0, 25, 50, 75, and 90%) were found to form 18 groups in a linear discriminant analysis; 11 of these contained a single gasoline, while the other 7 groups contained 2 to 6 gasolines.

Recently, Petraco et al. [18] studied the performance of a variety of multivariate statistical techniques in order to discriminate between 20 retained liquid gasoline samples from fire investigations. They selected

15 peaks from the chromatogram as input for statistical analysis. The 15 peaks were selected based on their consistent vapor pressure up to 75% evaporation. In order to create groups, a number of replicated measurements were made per gasoline.

### 1.3. Scope of the present study

In the present study the goal is to obtain numerical values for LRs calculated for the comparison of evaporated gasoline residues to other evaporated gasoline residues and unevaporated gasolines. Three methods to calculate LRs are presented. The methods differ in the features used to discriminate between gasoline residues and in the statistical approach used to obtain LRs. Two of them build on the literature on classification of evaporated gasoline residues and the forensic statistical literature. In the present study an automated procedure was developed for selection of peak area ratios with high discriminative value. The third comparison method has not been published previously in the literature on gasoline comparison.

The contribution of this paper is twofold. 1. Introduce the LR-approach to the field of forensic gasoline comparison. 2. Take a first step in the creation of computer-based methods in order to assign an evidential value to gasoline comparisons for forensic purposes, by accounting for evaporation.

## 2. Materials and methods

### 2.1. Hypotheses

In this work source level hypotheses are addressed [19]. Different-source gasoline samples are defined as either coming from different petrol stations or from the same petrol station that has been refilled in the meantime. Same source gasoline samples come from the same petrol station and refill. This definition of the same source and different source hypotheses in this way is in accordance with the experience of forensic experts on gasoline comparison at the NFI: gasoline at the tank of a petrol station is relatively stable in between refills.

In casework however, the relevant source of gasoline is at the person level. This is because different people who have collected gasoline from the same tank and refill are considered as different sources by the court. While gasolines from these persons should be considered as from a different source in casework, they are defined as from the same source in our dataset.

In order to obtain a more relevant dataset for casework, a survey of gasoline samples at people's homes would be preferred. However, for the current purpose of assessing and comparing the performance of three different LR-methods the current dataset is appropriate. It is not the goal of the present work to obtain a LR-method to be used in casework, but to show the feasibility of LR-methods to the comparison of evaporated gasolines.

### 2.2. Data

Samples of gasoline were obtained by repeatedly collecting samples at 15 petrol stations in the region of The Hague in the Netherlands. At a petrol station gasoline was collected at one or two fuel pumps. When two fuel pumps were used, Euro 95 gasoline was collected from one fuel pump, and a high octane grade gasoline was collected from the other. The time between each sampling was one week or more and it was checked that in between two collections the fuel pumps had been refilled. Samples were collected from July to October 2009 (189) and in July 2010 (29) and September 2010 (29). The high octane grade fuels contained 7 types of gasoline. The 15 petrol stations were of 9 different brands: BP, Esso, Gulf, Shell, Tamoil, Tango, Texaco, Tinq, and Total. A total of 258 samples of gasoline were collected.

Evaporated samples (126) were prepared from 42 of the 258 unevaporated gasolines, by evaporation of unevaporated gasoline

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