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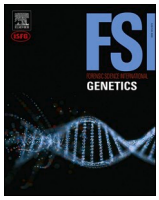

Case report

Driver or passenger? Use of a Bayesian network for the evaluation of DNA results in a fatal car accident

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ABSTRACT

This article presents a case where the issue was to determine who was the driver and who was the passenger at the time of a fatal car accident involving two persons, one of whom died in the accident. The presence of the two persons in the car was not contested, only the mechanisms that led to the deposition of the DNA (i.e., the activities) were. To our knowledge, few cases are evaluated considering the alleged activities. The reasons for this include the lack of knowledge, and data, as well as the difficulties encountered for the formulation of conclusions. In this case report, we present the architecture of the Bayesian Network (BN) used to evaluate the DNA results of the traces recovered from the steering wheel, driver's and passenger's airbags. The following propositions were considered: "The person of interest (POI) was driving the car and the alternative person (AP) was the passenger at the time of the accident" or vice versa. We discuss the assumptions that were made and how data from the literature was used to parametrize into the BN. A likelihood ratio of the order of 90 was finally assigned. The statement proposed to the mandating authority indicated that, given the information that was made available to us, our observations were of the order of 90 times more probable if the POI was driving the car at the time of the accident rather than if the AP was. A sensitivity analysis was performed (5000 simulations): this shows that our likelihood ratio is robust.

1. Introduction

In a car accident, when the presence of the occupants is not contested, evaluating the DNA results given (sub-)source level propositions with regards to the proposed occupants is not required, nor meaningful. Indeed, the question of interest is not from whom the DNA comes but relates to the mechanisms that led to the possible deposition of the DNA (i.e., the activities) [1,2].

Many experts will be asked questions about DNA transfer (persistence and recovery) in court. However, while a formal and documented evaluation considering activity level propositions is recommended [1, 2], it is not general practice [3], except in some countries such as in the Netherlands [4]. There may be many reasons for this:

(1) The lack of education and knowledge to carry out such assessments [3],
(2) The belief that forensic scientists would be usurping the role of the court by giving an opinion on their results given the alleged activities [5],
(3) The concerns regarding the scientific soundness of the approach itself, especially with regards to the validity and the applicability of the data (i.e., how close are the published data to the case at hand, do we have enough data to support a robust assignment of probabilities). These are addressed in detail in Biedermann et al. [5].

We understand the concerns regarding the availability of data about transfer, persistence, prevalence and background DNA. However, we note that, whether the data are relevant to the case at hand (i.e., chemistry used, experimental design) and whether the data are sufficient or not, is a professional call that needs to be made by a professional (i.e., someone who has had specific education on that topic). If there is

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no knowledge or data, then it is as important to convey this information to the fact finders: they should be aware that in such cases, if the source of the DNA is not contested, then the DNA findings cannot help to address their issue.

The publication of case reports can help dissipate some of these concerns and are complementary to data publications. To our knowledge, few case reports presenting the interpretation of DNA findings considering the alleged activities have been published [6–8] and we take the opportunity to do so for one case.

This paper presents how DNA results were evaluated and reported in a case where the factfinder had to determine whether it was the person of interest (POI) or the alternative person (AP) who was driving the vehicle at the time of the accident. The POI is the person suspected driving the car during the car accident and the AP is the alternative person involved in this accident. The POI is the son of the habitual driver, his father.

We first present the pertinent case information made available to us, the issue with which DNA analysis could help with and the formulation of the propositions. We then explain how missing information was handled and discuss the required assumptions that were made. The construction of a Bayesian Network (BN) allows capture of the dependencies between the variables and we present the data used to inform the conditional probability tables (CPTs). In the *DNA results evaluation* section, we take advantage of the BN to evaluate the DNA results obtained. Finally, using sensitivity analysis, we evaluate the impact of paucity and of new published data on our LR.

2. General case information and assumptions

The information provided by the police and initially available was as follows: two persons (the person of interest (POI) and the alternative person (AP)), borrowed the car of POI's father for a day trip. They drove to their location in the morning and several hours after (in the afternoon), on their way home, they had an accident. AP died in the accident and POI was injured but alive. Both individuals were found outside of the car when the police arrived on site. It was unclear who was driving at the time of the accident. To help determine whether it was the person of interest (POI) or the alternative person (AP) who drove the vehicle, DNA swabs were taken from the airbags and the steering wheel. DNA analyses were performed, and results assessed given the following two propositions:

- POI was driving the car and AP was the passenger at the time of the accident.
- AP was driving the car and POI was the passenger at the time of the accident.

In this case, we are unaware if other type of forensic work has been undertaken on the car that may have helped to address the issue (footwear mark on the pedals, fibers on the seats and car parts, fusion marks on plastic car interior surfaces).

To assess the findings, further information about the activities and the timings was gathered from the police. We were informed that the car was in good condition (e.g., both seatbelts were functional prior to the car accident) and that AP had never driven the car before the accident. The POI drove his father's car from time to time. On the morning of the accident, the POI was driving the car and AP was in the front passenger seat. Their location was about 30 minutes from the POI's house. In the afternoon, it was established they had driven for about 10 minutes when they crashed. The two occupants of the car were outside the vehicle when the police arrived. The POI did not remember how they got out of the vehicle: it was not known whether one or both were ejected because of the impact, if they got outside by themselves, or helped one another. The pictures of the car after the accident, showed that the passenger's seatbelt was broken and the windshield dislodged. It was assumed by the police that the seatbelt had broken upon impact, and that at least one of the persons had gotten out through the windshield. As the driver's door was blocked by a tree, neither the POI, nor the AP could have gotten out of the car using the driver's side. They had either gotten out by the passenger's door or through the dislodged windshield. Based on the crime scene investigation, the police favored that the persons probably got out through the windshield.

To cope with the lack of information, the following assumptions were made, based on our understanding of the case. These were submitted to the police service and the prosecutor for approval. They were also clearly disclosed in the evaluative report:

- Given the car damage and given that they knew each other, it was considered that both were riding up on the front seats.
- Since the POI and AP were unable to get out of the car using the driver's side, the passenger had not touched the driver's airbag.
- The driver, whether AP or POI, was not wearing gloves.
- The source of the DNA is not disputed, (i.e., AP and/or POI are the source of the DNA traces when showing compatibilities with their respective DNA profiles).
- As no blood spatters were observed in the car, it was assumed that the DNA recovered was not from blood. The negative OBTI-Blood test, performed by the police, supported this assumption. No additional test was requested to the forensic genetics' laboratory.
- We have considered that the accumulation of the POI's DNA on the steering wheel due to previous use of the car, is negligible compared to the DNA potentially transferred during the outward journey. We have also assumed that multiple touches result mainly in accumulation of DNA (i.e., we have not considered existing DNA removal in our model)

Statement writing depends on the case and on local practice. However, they should adhere to the general desiderata and the principles of interpretation [9]. Statements should disclose the reasoning of the scientists in a transparent, balanced, and logical way. The context of the case, the available information and the assumptions ought to be disclosed in the report. Besides, evaluation depends on the case information, our understanding of them, and the adopted assumptions. Hence, as suggested in several guidelines [1,2], we underlined this point in our report with the following caveat:

"Our evaluation is conditioned by the information that has been given to us and our assumptions. In the event that this information is not correct, or if new elements become known, a new interpretation will be necessary."

3. Bayesian network

The forensic community recommends evaluating DNA findings using a likelihood ratio (LR) [1,2], informed by published data, experience, and personal knowledge. When transfer phenomena are complex, as in this case, BNs are a particularly useful tool to model the intertwined dependencies and uncertainties. A BN consists of two main components: a graphical component which is the structure (variables and dependencies between each variable) and a quantitative component which are the conditional probability tables (CPTs) informed with data coming from experiments (published or not) and knowledge (refer to [10] for a review of the use BNs in forensic science). One added advantage of BNs is that they allow modelling of complex cases that may include multiple forensic findings. This section describes the construction of our BN in this case and how it was conveyed in our statement.

The BN (available in Appendix 1) was developed with HUGIN researcher version 8.8 (www.hugin.com) [11] using the generic template developed by Taylor et al. [12].

DNA swabs were collected from eight locations (i.e., the door-opening lever of passenger 'side, the outside door release handle of driver's side, the seat belt buckle of driver's side, the door-opening lever and internal door release handle of driver's side, the steering wheel, the gear knob, the passenger airbag, the driver airbag). Reportable DNA

profiles were only obtained for the passenger airbag, the driver airbag, and steering wheel. In the constructed BN, only the results from these three items were considered. Indeed, for our case, the probability of observing no reportable DNA profiles for the other items is the same given both propositions; these results are thus uninformative (i.e., they do not provide any information on whether POI or AP was driving the car at the time of the accident). It should be noted that the absence of DNA is not always uninformative, and this observation need to be assessed case by case.

3.1. Graphical component

Fig. 1 shows the BN used to evaluate the DNA results in the car accident case.

According to the case information, it is undisputed that POI drove the car on the morning of the accident on the outward journey and that AP was the passenger. This is why there is no arrow between Node 2 and Node 1. The possibility of direct transfer of POI's DNA (Node 5) and indirect transfer of AP's DNA (Node 6) onto the steering wheel during the outward journey need to be considered. As the airbags were deployed at the time of the accident, the possibility of DNA transfer to the airbags during the outward journey is ignored.

If the POI was driving the car (Node 3) and AP was the passenger at the time of the accident, then we need to consider the following transfer (persistence, recovery and DNA detection) mechanisms:

- POI's DNA may or may not be directly transferred to the steering wheel (Node 8) and to driver's airbag (Node 12)
- POI's DNA may or may not be indirectly transferred to the passenger's airbag because of interactions between AP and POI (Node 15)
- AP's DNA may or may not be indirectly transferred through interactions between AP and POI to the steering wheel (Node 9) and to the driver's airbag (Node 13)
- AP's DNA may or may not be directly transferred to the passenger's airbag (Node 16)

Conversely, if AP was driving the car and POI was the passenger at the time of the accident

- AP's DNA may or may not be directly transferred to the steering wheel (Node 9) and to the driver's airbag (Node 13)
- AP's DNA may or may not be indirectly transferred to the passenger's airbag because of interactions between AP and POI (Node 16)
- POI's DNA may or may not be directly transferred to the passenger's airbag (Node 15)
- POI's DNA may or may not be indirectly transferred to the steering wheel (Node 8) and to driver's airbag (Node 12)

The results obtained from the driver's airbag influence our expectations for the steering wheel's result, (i.e., if a single source DNA profile aligning with the DNA profile of an individual is obtained from the driver's airbag, this increases the probability to observe the same DNA profile on the steering wheel and vice versa). Thus, arrows between driver's airbag and the steering wheel (between Nodes 8 and 12, and between Nodes 9 and 13) were added. However, the results obtained on the driver and passenger airbag can be considered as conditionally independent. It may be confusing, knowing that if POI drove the car at the time of the accident, it means that AP is the passenger. However, this "dependence" is captured through the proposition node (Node 1). Therefore, no arrow was added between airbags (between Nodes 12 and 15, or between Nodes 13 and 16).

3.2. Quantitative component

This subsection presents the data used to inform the Conditional Probabilities Tables (CPTs). In Appendix 2, we show how to use experiments produced by another laboratory. We base our probabilities on experiments and expert knowledge. When a specific outcome was not observed (count of 0), we have added default prior counts as in [13].

3.2.1. Steering wheel

Pun [14] conducted a study on the DNA results obtained from various areas of a car, including the steering wheel, for different situations such as:

- The POI is a regular driver and drove the car last.
- The POI is a regular driver of the car, but not the last driver.
- The POI is a passenger.

This study allows to inform Nodes 5 and 6 (whether POI's DNA and AP's DNA transferred, persisted and was detected on the steering wheel following the outbound trip during which the POI was the driver), and nodes 8 and 9 (whether POI's DNA or AP's DNA transferred, persisted and was detected on the steering wheel during the approximately 10-minute return trip).

3.2.2. Airbags

Grubwieser *et al.* [15] published data from real cases on the DNA results obtained from airbags deployed following car accidents. The DNA results were detailed for 7 passenger's airbags and 8 driver's airbags. This data enabled us to inform Nodes 12 and 13 (whether DNA

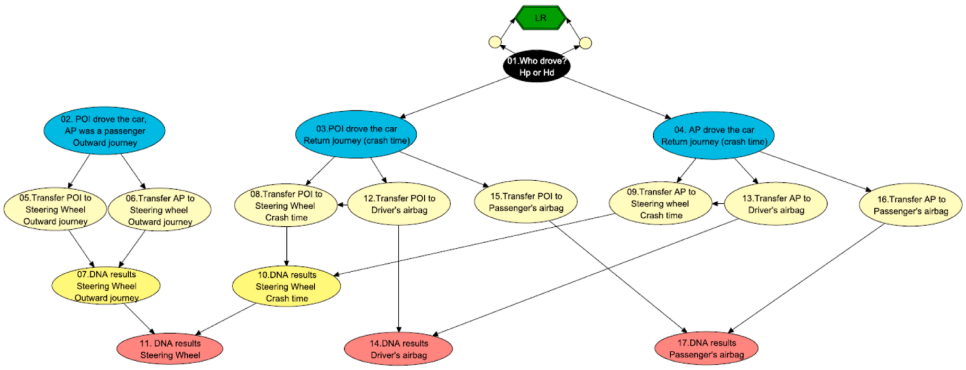

Fig. 1. Bayesian Network of the car accident case. The green hexagonal node and the two adjoining yellow circles are used to calculate the value of the likelihood ratio (LR); the black node is the propositions node (i.e., the disputed activities); the blue nodes detail the activities that occurred (POI drove the car during the outward journey, either POI or AP drove the car at the time of the accident), and the red nodes represent the results. The pale yellow nodes are intermediate nodes to account for DNA transfer, persistence, recovery and detection. The stronger yellow nodes are intermediate nodes allowing to combine the information from several nodes, as to not overload the results nodes (in red).

from the POI and AP transferred, persisted and was detected on the driver's airbag) and Nodes 15 and 16 (whether DNA from the POI and AP transferred, persisted and was detected on the passenger's airbag).

3.2.3. Observations

How we choose to describe the states of each variable (e.g., presence/absence; none/major/minor/other; quantity of DNA), depends on the level of detail in the results provided in the published data. Given the data available to us, DNA observations were defined using the following categories:

a) Major POI-Major AP (with/without unknown contributors)
b) Major POI- minor AP (with/without unknown contributors)
c) Minor POI-Major AP (with/without unknown contributors)
d) Minor POI-Minor AP (with major unknown contributors)
e) POI only (without AP, with/without unknown contributors)
f) AP only (without POI, with/without unknown contributors)
g) No POI, no AP (only unknown contributors or no DNA)

The category "Major POI-Major AP (with/without unknown contributors)" combines the situation where POI and AP align with major contributors and the situation where POI and AP are compatible with unresolvable mixture (e.g., 1:1 mixture). The category "Minor POI-Minor AP (with/without unknown contributors)" combines the situation where at least one unknown person is a major contributor and POI and AP align with minor contributors.

For major/minor definition, we have used the same rules as Carrara et al., 2023 [16], namely: "For mixed DNA profiles, the presence of a major contributor was considered when its contribution, determined with STRmix™, was greater than 70 %, 60 % and 50 % in mixed DNA profiles of 2, 3 and 4 contributors, respectively. In such cases, the other contributors were considered as minor contributors".

3.3. Description of the BN in the report

In our reports, we generally do not detail the BN, but disclose its existence and the source of the data and the studies used to inform its parameters. We describe how our LRs were assigned (per item and combining all the items). For example, in this case we stated:

"To assess the value of the results, a Bayesian network was built and informed by our knowledge and data from Grubwieser et al. (2004) and Pun (2016). The research by Grubwieser et al. provides information about DNA transfer on 8 driver airbags and 7 passenger airbags following an accident. In our assessment, we have taken into account the fact that this study contains a limited amount of data and that the analysis techniques date back to 2004. Pun's PhD thesis provides information on the persistence of DNA in a vehicle driven by a regular user, in a vehicle. Further information on the Bayesian Network, data and methods used is available on request."

An appendix (SM 2) is systematically prepared to act as laboratory case notes and can be transmitted upon request. This work is essential to allow for peer review purposes: it describes in detail how the BN was designed and how the CPTs were informed. However, the details of the BN and the conditional probability tables are quite technical: for this reason, we have taken the policy of not systematically including them in our report.

4. DNA results evaluation and reporting

This section shows how we reported the value of the observations based on the BN, given the available data, knowledge and information.

To assign the value of the findings in this case, we have considered the probability of the DNA results given the following pair of propositions:

- POI was driving the car and AP was the passenger at the time of the accident.
- AP was driving the car and POI was the passenger at the time of the accident.

We generally compute respectively the probability of the DNA results given one proposition and the probability of the same results given the alternative. The likelihood ratio is obtained by the ratio between these two probabilities (i.e., ratio between numerator and denominator). The probability of the DNA results has been assigned based on published data and our knowledge on transfer and persistence. This probability represents our uncertainty regarding the observation of a DNA result considering that a specified activity has taken place. For example, if we almost always expect to observe a single DNA profile if the specified activity has taken place, then the probability of this result is close to one. If, in our opinion, this result is very unlikely, if the specified activity has taken place, then the probability of this result is close to zero. In all other cases, the probability varies between these two extremes.

In the statement, as much as possible, we try to avoid using jargon and scientific or technical notation.

In the following sections, as the source of the DNA was not an issue, when the DNA profiles of AP or POI align with the DNA profiles of the traces, we considered that the DNA is from AP or POI (see assumptions).

4.1. Results on the passenger airbag

A 3-person mixed DNA profile, with a major component aligning with the DNA profile of AP (61 % of the mixture) and a minor component characterized as not interpretable was obtained for the trace collected on the whole passenger airbag. This result can thus correspond to the state "AP only (without POI, with/without unknown contributors)" in the BN.

If POI was driving the car and AP was the passenger at the time of the accident, the probability of observing only AP's DNA on the passenger airbag is assigned as of the order of 51 %. If AP was driving the car at the time of the accident, observing only AP's DNA on the passenger airbag is not expected. Given the parameters retained in the BN, the probability of observing such a result is of the order of 8 %.

The LR assigned for the DNA results observed on the passenger's airbag is of the order of 6. This means that the findings are 6 times more probable if the POI was driving the car and AP was the passenger at the time of the accident than if AP was driving the car and POI was the passenger at the time of the accident.

Note: The reader will observe that 51 % divided by 8 % is 6.37. We tend to use of the logarithm of the LR as a measure of evidential weight as suggested by Good [17]. We share the opinion that precision (beyond one significant figure) in the LR is not needed for effective communication of the evidential weight to jurors [9]. Therefore, in the statement, we reported our LRs to one significant figure: the computed LR is 6.37, but our reported LR is 6.

4.2. Results on the driver's airbag

On the driver's airbag, a mixed DNA profile was observed, with the DNA profile of the POI aligning with the major contributor (72 % of the mixture), AP aligning with the minor contributor (23 % of the mixture), and a third unknown contributor (5 % of the mixture). This result can be classified as: "Major POI-Minor AP (with/without unknown contributors)".

If the POI was driving the car at the time of the accident, the probability of observing this result is of the order of 8 %. Note that this probability is low. Indeed, the presence of AP's DNA, even as a minor contributor, is not expected if AP was just the passenger.

If AP was driving the car at the time of the accident, the observation of POI's DNA as a major contributor and AP's DNA as a minor contributor on the driver's airbag is not expected either. The probability of this result is of the order of 0.8 %.

The LR assigned for the DNA result observed on the driver's airbag is

of the order of 10. This means that the findings are 10 times more probable if the POI was driving the car and AP was the passenger at the time of the accident, rather than if the situation was reversed.

4.3. Results on the steering wheel

A single source DNA profile with the same allelic designation as the DNA profile of POI was obtained on the steering wheel. This means that we describe the results in our BN as: "POI only (without AP, with/without unknown contributors)".

Based on the BN, if POI was driving the car at the time of the accident, knowing that he drove it in the morning and that a mixed DNA profile was observed on the driver's airbag, with POI as the major contributor and AP as a minor contributor, the probability of observing - on the steering wheel – only POI's DNA was assigned as of the order of 67 %. Here, to assign our numerator, we condition our results on the observations for the driver's airbag, as the results are not considered to be independent.

If AP was driving the car at the time of the accident, knowing that POI drove it in the morning and that a mixed DNA profile was observed on the driver's airbag, with POI as the major contributor and AP as a minor contributor, the probability of observing - on the steering wheel- a DNA profile aligning only with the POI is of the order of 44 %. As before, we condition our results on the observations for the driver's airbag. In this situation, the short driving time, (i.e., about 10 minutes) and the fact that the POI had driven the car on the outward journey, were important considerations when assessing the absence of DNA from AP.

The LR assigned for the DNA results observed on the steering wheel is of the order of 1. This means that the observations are as probable if the POI was driving the car and AP was the passenger at the time of the accident as if AP was the driver and POI the passenger. As such, the results on the steering wheel do not help discriminate propositions: they are uninformative.

4.4. Combination of the DNA results

Considering these findings jointly, using the Bayesian network, a LR of the order of 90 was obtained. We report the LR calculated by the BN. Depending on the case, there can be small differences between the multiplication of the LRs per item because of truncating effect (here from 60 to 90). This means that it is of the order of 90 times more probable to make all our observations if POI was driving the car and AP was the passenger at the time of the accident rather than if AP was driving the car and POI was the passenger at the time of the accident. Note that this does not mean that it is 90 times more probable that POI was driving the car at the time of the accident. Indeed, to make such a statement one would need to consider all the other elements of the case. To give an opinion on what happened is not the remit of the forensic scientist, but of the factfinder. DNA can only contribute to solving the issue, it is not sufficient on its own.

5. Discussion

5.1. Missing information and assumptions made in the case

Missing information is common in all forensic cases. The question is how to deal with that lack. Two categories of information can be distinguished:

- The one that is available through contacts with the appropriate services (e.g., Who owns the car?),
- The one that is unknown (e.g., Was the passenger seated in front or behind?).

Information that is available may be difficult to obtain. In general, the more information available, the more relevant case assessment will be. Every effort should be made to obtain this information, but procedures that avoid possible biases are also required [18,19].

One way of dealing with missing information, whether it is information that is available but could not be transmitted, or information that is unknown, is to make reasonable assumptions. It is important to disclose these assumptions in the statement so that if they are contentious, a new evaluation can be performed. We believe it is important to avoid listing multiple scenarios and assessing the results given each individual situation. Indeed, multiple LRs will be obtained, one for each situation, but for the same case. The reader of the statement may then be tempted to choose the propositions based on the LRs obtained, rather than proceeding in the correct order. The facts should guide the interpretation of the results [20]. Therefore, whenever possible, assumptions should be presented to the parties before the evaluation and statement are produced. It is essential to clarify in the statement that a new evaluation will be needed if the information changes. If multiple LRs given different case circumstances are presented, we recommend specifying that the evaluation should solely rely on the assumptions deemed reasonable by the court, and not on the LR values. It is however important to justify the assumptions, especially when they are based on the case information. While it is not our usual practice in casework, for the purpose of this article, we will discuss the potential impact of changing the assumptions below. However, it is not feasible nor desirable to consider every possible variation of each assumption (similarly to what has been published on propositions [21,22]), and thus we do not detail the exact influence of these changes on our LR.

The assumptions were disclosed in case we had misunderstood any key points or if new elements came to light:

- Passenger position: Given that only two individuals were involved, who knew each other, it was assumed that both were seated in the front. If one person had been seated in the back, this would impact our transfer probabilities.
- Glove use: Since, neither individual was wearing gloves after the accident, we assumed the driver, whether AP or POI, had not been wearing gloves. In this situation, the LR for the steering wheel is one. Moreover, if gloves had been worn, our transfer probabilities for the airbags would not be impacted and the overall LR would remain unchanged.
- Source of the DNA: Based on the DNA comparison and the undisputed presence of both individuals in the car (with no third party involved), we assumed that the DNA aligning with each individual was theirs. Given the rarity of the DNA profiles, considering uncertainty about the source of the DNA would have little effect on the overall LR.
- Exit route: From the photographs of the car damages, we assumed that the individuals could not have exited through the driver's side. If that had been the case, our transfer probabilities would require revision in the light of the new case information.
- Absence of blood: Based on the negative OBTI test, we assumed that the DNA did not originate from blood. If this assumption were invalid, it would alter our evaluation, as the data used are not valid for blood sources.

Regarding the assumption how DNA accumulation is modelled in our analysis (i.e., we did not account for DNA removal overtime), this was done for simplification purposes (similar to our assumption that the DNA is from the persons of interest). We do not expect that including DNA removal in our model would significantly impact on the overall LR.

5.2. Conditional dependencies between nodes

Without access to research data, it is difficult to judge if the variables can be considered independent or not (e.g., the results obtained for both airbags). If no dependency was considered between two variables, when it should have been, the LR value will often be larger than expected, which is not desirable. If in doubt, it is therefore best to model conditional dependencies even if following parametrization of the CPTs, this

has no effect on the LR.

5.3. Data used to inform the Bayesian network

Rightly so, DNA scientists often have concerns about data: first are they relevant to the case at hand (i.e., how close are the data to the case), and second is the disclosed knowledge sufficient for a robust assessment. There is no easy answer, however, as advocated in Biedermann et al. [5], the knowledge is what it is and so is the issue. Unless more experiments can be done for the case at hand, if we do not assess our results taking into account the possible transfer routes, who will? And, if we do not perform an analysis, how can we establish if the results are helpful or not? If the data are limited, then this will be shown in the magnitude of the LR.

Although the data used in our evaluation [14,15] was obtained under varying conditions, we are of the opinion that they provided valuable information to assign our probabilities [23].

Besides, since the time the present evaluation was performed, two studies about the prevalence of DNA from drivers and passengers on steering wheels were published [24,25]. Boyko *et al.* [24] collected five swabs on the steering wheel of each of the four cars exclusively driven by the same driver for 3 months. De Wolff *et al.* [25] collected three swabs on the steering wheel of each of the five cars driven by the same driver with, most of a the time a passenger who may be different. These studies, combined with the one of Pun [14], allowed us to update the conditional probabilities tables for Nodes 2 and 6 related to the steering wheel (see Appendix 3). This new data did not change our LR that was still of the order of 1 for the steering wheel. Using different studies or combined different studies had no impact on the LR. It is reasonable to conclude that, for the steering wheel, the evaluation is robust over time.

Since only a few airbags were studied in Grubwieser et al., sensitivity analysis could be conducted to assess the impact of data scarcity on the LR [26,27]. Depending on the method used, it also gives information on how much data is enough. When the case occurred, we did not perform such an analysis as it was too complex. However, Taylor et al. [27] recently developed an application (https://cchampod.shinyapps.io/BN_sensitivity/) that allows to perform sensitivity analysis easily by considering the number of experiments. We have assumed that AP and POI would have the same probability of depositing DNA (same donor status), therefore nodes 12 and 13 should theoretically be resampled in the same manner. However, the application available for sensitivity analysis assumes an independence of datasets used to inform each node (i.e., independence of datasets for node 12 and node 13, whereas they should be dependent). We expect this to have a conservative effect in the sense that more variability in the LRs is expected than if we had used the same dataset. Using the procedure described by these authors, we were able to show that the reported LR falls within the 95 % coverage of the simulated LRs, in log10 between [0.85 and 3.96] following 5000 simulations (Fig. 2). This corresponds to LRs of 7 and 6000, compared to our reported LR of the order of 90. The 95 % coverage of the simulated LRs does not fall within one order of magnitude from the average LR, which was a possible criterion proposed by Taylor et al. [27] to consider a range robust. Although, sensitivity analysis suggests, not surprisingly, that more data would be welcomed, it also shows that the order of magnitude quoted in the report is robust in the sense that it has limited opportunity to mislead the court. Moreover, the size of the datasets/knowledge used to inform our probabilities were clearly disclosed in the report and the limitations presented. Therefore, taking into account that the Application assumed independence of datasets whereas our evaluation did not, we are of the opinion that the order of magnitude of 90 best reflects the value of the findings and is helpful to the criminal justice process.

The files required for the sensitivity analysis are available in Appendices 4 and 5. Appendix 6 contains the report generated by the application.

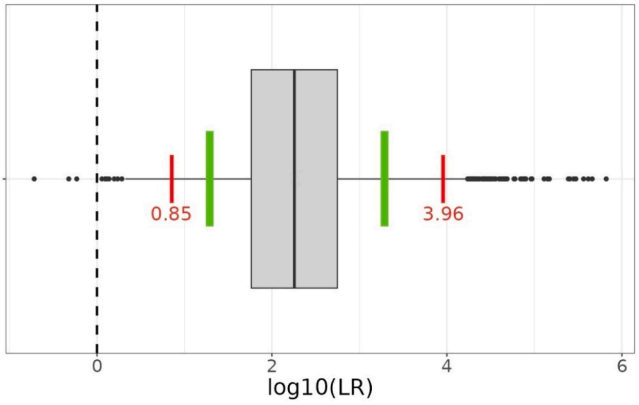

Fig. 2. Results of sensitivity analysis by performing 5000 simulations. The red lines indicate the boundaries of the central 95 % quantile of the resampled dataset. The green lines represent an interval that differs by one order of magnitude from the average LR.

5.4. Reporting

Different options can be adopted when reporting the value of the findings:

- To indicate only the LR for the all the samples jointly ("overall LR") or to also report the LR for each DNA result.
- To report the numerator and the denominator separately and then combined them in a ratio or only report the LRs.
- To present posterior probabilities based on LR obtained in the case as a function of different prior probabilities or not engaging in that illustrative update mechanism.
- To add a verbal qualifier to the LR or not [28].

In our statements, we disclose and explain the numerator, denominator and LR obtained for each result and we then report the "overall LR" combining all the findings. In our opinion, this allows for greater transparency and helps to better convey the meaning of the different findings. It shows which result has the most value and if there are contradictory or not.

We have also decided, for the evaluation of findings given activity level proposition, to present a table to demonstrate why DNA findings are not sufficient on their own and what is the impact of the other information in the case. In the table below, we present how posterior probabilities vary in function of the LR obtained in the case and different examples of prior probabilities. (Table 1). This illustrates how the non-DNA information impacts the probability that the POI drove the car at the time of the accident or not, with the LR obtained in the specific case.

We do not include verbal qualifiers because they are based on a convention and, except for the value of 1 where there seem to be a consensus, verbal equivalence tables vary. We are in the opinion that a verbal qualifier is not very useful and use Table 1 instead.

Table 1
Posterior probabilities combining LR and prior probabilities.

Prior probability that POI drove the car at the time of the accident (or not) based on elements of the case other than DNA	Likelihood Ratio obtained in the case	Posterior probability that POI drove the car at the time of the accident (or not) based on elements of the case and DNA
10 % (90 %)	90	90 % (10 %)
50 % (50 %)	90	98 % (2 %)
90 % (10 %)	90	99 % (1 %)

6. Conclusion

Whether DNA results need to be assessed in the context of the alleged activities is mostly not a question of if or when, but a question of how. Indeed, questions of transfer are already discussed in court with or without the help of DNA experts in that field. As for all disciplines, it is paramount that only trained and qualified scientists help answer questions regarding transfer of DNA. Confidence in the robustness of the results should be warranted by quality procedures, and the provision of case specific data. The publication of case reports shows if practice aligns with published guidelines and act as proof of concepts. Having a portfolio of cases studies [29], could also save time and resources, as one of the difficulties is to locate data that will be meaningful in the specific case. Also, the establishment of a collection of Bayesian networks to deal with different cases will provide a basis for the next cases.

In this article, we have described how we have assessed DNA results obtained in a car accident case. When pre-assessing cases, the first step is to gather task relevant information needed to perform an evaluation: in general, important information regarding the timing or the activities will be missing in the submission, as in this case. It is important to ensure good communication between investigators and scientists, so that only task relevant information is provided. There will always be information that will remain unknown, and assumptions will have to be made. Ideally, in the pre-assessment stage, they should be discussed with parties involved and disclosed in the report. Regarding the methodology used for evaluation, the use of a BN allows to account for the dependencies between the factors of interest. It computes the value of the results for each of the items in a transparent way. By sharing how we reported this case, we hope that this article will prove useful to other DNA scientists who report the value of DNA results in the context of the activities.

CRediT authorship contribution statement

Tacha Hicks: Writing – review & editing, Methodology. **Vincent Castella:** Writing – review & editing, Supervision, Resources, Investigation. **Christophe Champod:** Writing – review & editing, Software, Investigation. **Séverine Delémont:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization. **Lydie Samie-Foucart:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

No conflict of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fsigen.2024.103166.

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