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Utility of the Clue. Formalisation of the decision to analyse a trace and insights into the evaluation of the investigative contribution of forensic science

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PhD Thesis

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Formalisation of the decision to analyse a trace and insights into the evaluation of the investigative contribution of forensic science

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Abstract

Although providing significant contribution to the investigation and the prosecution, the effectiveness of forensic science has been challenged by several studies, indicating that it is either scarcely used and thus not relevant, or when it is used, its effects on case processing are minor. The majority of the studies focussed on an understanding of forensic science as the application of scientific techniques to the matters of court. Consequently, the contribution of forensic science was determined for judicial steps of the criminal justice process, such as suspect arrest, charging or conviction. The proposed remedies for its infrequent use or alleged ineffectiveness focussed mainly on technical developments or managerial guidelines.

The concept of utility of the clue, defined as added value in terms of information gained through the analysis of the trace, is suggested to be used in two manners: 1) as decision factor in the decision to analyse a trace, and 2) as performance measurement indicator to assess the contribution of forensic science in the criminal investigation. Through the applied methodology, combining both quantitative and qualitative approaches, it was possible to formalise the decision-making process, with a particular focus on the decision to analyse a trace. In addition, the factors influencing this latter step could be determined.

In a first study, the crime scene attendance strategies of burglaries in three Swiss cantons were determined to be very variable and depending on the organisation, the resources and the constraints in place (Neuchâtel, Genève et Vaud, study period 2012–2013). Then, the analysis rates for different types of traces were compared, and it could be concluded that, except for biological traces, most triaging occurs already at the crime scene based on visible, qualitative aspects, including the pertinence and the expected utility of the traces. Furthermore, an additional comparative study was carried out to determine the analysis strategies depending on the type of offence. Analysis rates of biological traces for burglary, robbery and homicide cases in the canton Vaud in the same study period were examined. In burglaries, the selection of

traces for analysis is anticipated to the collection stage, as nearly all collected traces are analysed. However, the number of collected traces per case is low. In contrast to homicides, where a large number of traces is collected, a more severe triaging procedure is performed. Due to the small number of cases per year, this type of cases was nonetheless not chosen as study object. Robberies appeared to be a hybrid form regarding trace processing between burglaries and homicides and thus a good compromise for the in-depth study of the decision to analyse a trace.

Through decision tree modelling, the factors influencing the decision to analyse a trace and the decision to analyse a trace first were determined considering robbery cases. Indeed, the utility dimension influences this decision, as the consideration of previous information, whether through trace analysis or police enquiry, is taken into account in the statistical models. Contrary to the recurrent findings in the literature, financial aspects of the analysis and physical elements of the trace (the type of biological trace and the matrix it was recovered from) could not be confirmed to influence these decisions in a uniform way.

Evaluating the contribution of forensic science to the criminal justice system was performed by extending the application of the concept of utility to an assessment of the contribution of the clues *a posteriori*, once all analyses have been performed and the results of the analyses are known. The predominantly recognised dimension of utility is for identification purposes. Contrarily to the literature findings, the principal aim is thus not to build a case against (an already known) suspect, i.e. confirmation, but to contribute new information. This result might be a consequence of the favourable context for DNA analysis in Switzerland, where a trace analysis is performed within several days. Other than identification and confirmation, which are mainly valid for biological traces and fingermarks, a panoply of dimensions of utility could be observed for all types of traces: linking cases, determination of the implication of suspects in collective crimes, reconstruction of events, aid in the legal qualification of the case, exclusion of suspects, catalyst of information in the enquiry (e.g. in interrogations), catalyst of traces during the crime scene investigation.

This study has shown that when recognising the role and integration of forensic science as equal partner in the criminal justice process, starting at the crime scene and centring around the trace as vector of information, the use of forensic science can substantially contribute to the criminal investigation showcasing a panoply of dimensions of the utility of the clue. This starts by acknowledging the decision-making process regarding trace processing, filtering out traces along every step, highlighting the benefits of an approach completely integrating the different aspects of the criminal enquiry.

Résumé

L'efficacité de la science forensique a été remise en question par plusieurs études, relevant qu'elle n'est soit que très peu utilisée ou que, lorsqu'elle est utilisée, son impact est négligeable. La majorité de ces études démontre une compréhension de la science forensique comme étant une application de techniques scientifiques à des fins judiciaires. Par conséquent, l'évaluation de la contribution de la science forensique s'est limitée à l'impact aux étapes judiciaires de la procédure criminelle, notamment l'arrestation du suspect, sa mise en accusation ou sa condamnation. Les remèdes proposés contre l'usage peu fréquent ou l'inefficacité présumée se concentrent tous sur des développements techniques ou des directives managériales.

L'utilité des indices, définie comme plus-value en terme d'information acquise par l'analyse de la trace, est proposée comme facteur déterminant pour la décision d'analyser une trace ainsi que comme indicateur de la contribution de la science forensique dans l'enquête criminelle. La méthodologie appliquée, combinant des approches quantitative et qualitative, a permis une formalisation du processus décisionnel, avec une emphase sur la décision d'analyser une trace et la détermination des facteurs influençant cette décision.

Une première étape consistait en l'étude des stratégies d'intervention de scène de crime des unités forensiques dans trois cantons suisses (Neuchâtel, Genève et Vaud, période d'étude: 2012–2013). Il a été constaté que ces stratégies sont très variables et dépendent entre autres de l'organisation, des resources et des contraintes en place. Ensuite, les taux d'analyses de différents types de traces ont été comparés et il a pu être conclu que, à l'exception des traces biologiques, le tri des traces à analyser est déjà anticipé lors de l'investigation de scène de crime. Cette sélection se fait sur la base des aspects visibles, qualitatifs des traces, dont la pertinence et l'utilité présumée. De plus, une étude a été effectuée afin d'identifier les différences concernant les taux d'analyse des traces biologiques en fonction du type de délit investigué. Les taux d'analyse des cas de cambriolages, brigandages et homicides

dans le canton de Vaud ont été examinés. En ce qui concerne les cambriolages, presque l'entièreté des traces prélevées est analysée, ce qui corrobore le constat que la décision d'analyser une trace est anticipée et prise au moment du prélèvement de la trace. Cependant, le nombre de traces prélevées par cas est relativement bas pour ces cas, en comparaison au cas d'homicides. En effet, pour ces cas, un grand nombre de traces est prélevé, par contre, une étape de tri plus sévère est effectuée au moment de la décision d'analyser. Ce type de délit aurait pu alors faire l'objet d'une étude plus approfondie, toutefois le nombre de cas par année étant relativement bas, la procédure de collecte de données aurait été difficile. Les cas de brigandages constituent une forme hybride en ce qui concerne la stratégie d'analyse entre les cas de cambriolages et les cas d'homicides. Donc, ces cas ont été sélectionnés pour l'étude approfondie de la décision d'analyser une trace.

Le premier objectif principal consistait en la formalisation et la détermination des éléments influençant la décision d'analyser une trace biologique dans les cas de brigandages. Par des modèles statistiques, des arbres décisionnels, les facteurs influençant la décision d'analyser une trace et la décision d'analyser une trace en premier ont pu être déterminés. Comme la dimension d'utilité a une influence sur ces décisions, ces modèles statistiques sont pertinents car ils permettent de tenir compte de l'information préalable considérée, que ce soit par le biais de l'enquête ou d'une exploitation préalable d'autres traces. Contrairement à ce qui est énoncé dans la littérature, les facteurs financiers et les aspects physiques de la trace (type et matrice de trace biologique) ne se sont pas révélés être des éléments décisifs pour la décision d'analyser une trace dans ce type de délits.

L'évaluation de la contribution de la science forensique dans le processus judiciaire a été le second objectif principal. Elle a été réalisée par l'application du concept d'utilité, par extension, à l'appréciation de l'utilité *a posteriori* des indices, après l'analyse des traces et l'obtention des résultats de ces analyses. L'utilité première se concentre sur l'identification d'un suspect. Contrairement aux résultats énoncés dans la littérature, l'objectif principal n'était donc pas de bétonner le cas autour d'un prévenu déjà connu, mais plutôt de fournir de nouvelles informations. Ce résultat doit être considéré dans le contexte suisse qui est favorable aux analyses ADN, les résultats d'analyses étant disponibles en quelques jours. Au-delà des dimensions d'utilité d'identification et de confirmation, qui prévalent surtout pour les traces biologiques et les traces digitales, une panoplie de variantes de dimensions d'utilité a pu être constatée: création de liens entre affaires, détermination de l'implication de suspects dans un délit collectif, reconstruction des événements, aide à la qualification légale du cas, exclusion de prévenu(s), catalyseur d'information dans l'enquête (par exemple lors de l'audition), catalyseur de traces lors de l'investigation de scène de crime.

Cette étude a montré que par la reconnaissance de son rôle et de son intégration comme participant à part entière dans la procédure criminelle, initiée dès la scène de crime et centrée sur la trace comme vecteur d'information, la science forensique peut contribuer de manière cruciale à l'investigation criminelle comme en témoigne sa panoplie de dimensions d'utilité. Ceci passe par une valorisation des différents processus décisionnels qui influent sur l'exploitation du potentiel informatif des traces, en particulier la sélection des traces à analyser. Cela met en lumière les bénéfices d'une approche pleinement intégrée dans les différentes dimensions de l'enquête criminelle.

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Contents

1 Foreword

The investigation and prosecution phases of the criminal justice system are under pressure from multiple sides; on the one hand, investigators and prosecutors, constrained by procedural rules, need to deliver quick results (i.e. identify suspects, charge the right culprit), on the other hand, financial pressure restricts available means to reach these results (Renard, 2011; Renard and Jeuniaux, 2012). Although providing significant contribution to the judicial inquiry, the practice of forensic science is strongly affected by these budget constraints as it often entails costly and (sometimes) time-consuming analysis steps (Home Office, 2005; Burrows et al., 2005). Among the several decision nodes, the triaging decision – deciding which traces should be analysed and which not – is especially important when handling large amounts of traces with limited resources. It consists of a means of distributing the personal and financial resources to the most important cases. The contribution of forensic science in the investigation is conditioned by different stages of the decision-making process, such as the decision to proceed to an investigation at a scene, to collect and to analyse traces (Bitzer et al., 2016) (see also Chapter 3 Criminal Justice System and its Actors). As the question of efficiency and effectiveness of forensic science is increasingly of interest due to these pressures, this decision phase becomes the focal point of material trace processing. Although the decision to use a trace in order to extract information from it, together with the factors leading to this decision, have been recognised of utmost importance regarding the usefulness of forensic science in the investigation (ANZPAA-NIFS, 2013; Brown et al., 2014; Mapes et al., 2015; Milon, 2013; Albertini and Milon, 2013), it has been the subject of very few studies thus far.

Often, policy makers, police or forensic managers establish strategic guidelines, implemented through protocols and procedures for deciding which traces are analysed, stemming from financial and performance pressure (Mapes et al., 2015; Milon, 2013). These guidelines privilege traces with the highest analytical yield, i.e. traces that, after analysis, have the highest chance of delivering an ideal (straightforward) result. In contrary, the integrated practice of forensic science needs to be founded on the exploitation of traces that present the highest utility, i.e. the potential to deliver an added-value of information, even if their analytical result is unclear or imperfect (Home Office, 2005; Burrows et al., 2005).

1.1 Objectives

The aims of this thesis were to identify how the above mentioned triaging step influences the management and the progression of the investigation and the trace processing. First of all, the decision-making process needed to be unfolded in order to display and understand the framework surrounding the triaging decision. Once this decision step identified, put into context and scrutinised, the structure of the interactions governing this decision is studied and formalised, focussing on robbery cases in the canton Vaud, Switzerland.

Through literature review, the trace processing procedure and the connected performance measurement indicators are examined. The concept of the utility of the clue is suggested as performance measurement indicator and decision-making factor for the use of forensic science in the investigation. This concept, along with the knowledge dimensions proposed by Ribaux et al. (2010b), constitute the basis for the determination of the factors under consideration when studying the decision-making process.

1.2 Thesis Structure

The structure of the thesis is outlined below. In chapters 2 and 3, the definition of forensic science and the framework we are working in are specified. Then follows a literature review of the existing performance measurement indicators, including a discussion about their limitations (see chapter 4). Subsequently, the concepts used in this study are presented, with a special focus on the utility of the clue (see chapter 5). Chapter 6 highlights applications of the concept of utility to the previously described decision-making process, more specifically the decision to analyse a trace. This application is then extended to the overall performance measurement of forensic science in the criminal investigation process (chapter 7). The last 2 chapters conclude with a discussion and synthesis of the theoretical concepts, their application and the findings (see chapters 8 and 9).

Chapter 2 From Forensics to Forensic Science

In order to understand the scope and utility of forensic science, the definition of forensic science needs to be clarified. Furthermore, its role and integration in the criminal justice system are discussed. This chapter describes what we are dealing with, what is the object we are studying and trying to evaluate the performance of.

Chapter 3 Criminal Justice System and its Actors

This chapter describes the legal framework in which forensic science is embedded. It explains the actors in the process as well as their roles and responsibilities. Furthermore, the decision-making process with all the triaging steps are highlighted. In order to understand, when and by whom forensic science can be applied, the legal framework and actors need to be clarified. In addition, the decisions involved in the criminal justice system need to be made explicit.

Chapter 4 Performance Measurement Indicators

This chapter deals with the performance measurement indicators suggested thus far; their validity, their limitations. The link is made with the diverging definition of forensic science, and thus, the very limited validity of its measured contribution.

Chapter 5 Influencing knowledge dimensions

The concepts used in this study are presented in this chapter. Special focus is on the concept of utility of the clue, with all its implications, conditions and limitations. We suggest the introduction of the concept of utility in the decision to analyse traces, i.e. traces are chosen for analysis based on their potential to deliver an added value in terms of relevant and novel information to the case, taking into account the information already available in that same case.

In addition, the knowledge dimensions suggested by Ribaux et al. (2010b) to influence the early stages of trace processing (crime scene attendance, search and collection of traces) are presented and, by extrapolation, adapted to the decision to analyse a trace.

Chapter 6 Utility and the decision to analyse a trace

In preliminary studies, the differences in intervention and triaging strategies in commercial burglary cases of three cantons of the Western part of Switzerland and the analysis strategies for different types of traces are determined. These serve as basis to create a working framework for the subsequent in-depth study.

The decision to analyse a trace is studied through statistical analysis of the analysis strategies of biological traces in robbery cases. The dependent as well as independent variables are presented and the influence of the knowledge dimensions as well as the utility dimension is assessed. This is achieved through decision tree modelling of the decision to analyse a trace and the decision to analyse a trace first.

In complementary analyses, the influence of some of the variables highlighted in the decision trees on the success, hit and pertinent hit rates of the performed analyses is determined. The success rate is the ratio of the number of analysed traces whose analysis yielded a positive result (a comparable profile) over the number of analysed traces. The hit rate corresponds to the ratio of hits generated from these positive results. Finally, the pertinent hit rate is the ratio of hits (suspect or victim), which are potentially useful to the case, compared to the overall number of hits.

Chapter 7 Utility and the performance of forensic science

The concept of utility of the clue is discussed as performance measurement indicator for the contribution of forensic science to the investigation. The actual utility *a posteriori*, once all analyses have been performed, is assessed on a case basis.

The expected utility *a priori* is presented as guide in the decision-making process. The expected utility *a priori* of the non-analysed traces is considered, in comparison to the information already available in the case. In addition, the expected utility *a priori* of analysed traces is highlighted in cases for which the actual utility *a posteriori* has changed from the initial consideration.

Chapters 8 Discussion and **9 Conclusion**

In these two concluding chapters, the overall contribution of forensic science in the criminal justice process, as determined through the research methodology developed in this study, is discussed in the context of the previously emphasised framework. The limitations and perspectives originating from this study are presented and discussed.

2 From Forensics to Forensic Science

In order to determine the performance and the use of a discipline, one needs to assure a common understanding of the central element in question. This research focusses on the utility of forensic science, considered as both performance measurement indicator and factor in the decision-making process regarding trace processing in the investigation. Forensic science is the central element, thus, the differences in definitions are reviewed and discussed. In particular, the definition and understanding of forensic science serving as basis for this study, as well as the connected integration models shaping the organisation and view of forensic science by police and laboratories, are specified and discussed.

2.1 Definition and integration of forensic science

The early definition of forensic science by Rodolphe Archibald Reiss (inaugural lecture in 1906) portrayed a very wide-ranging view encompassing "criminological aspects of criminal phenomena and situational studies, scientific and investigative methodology and reconstruction aspects afforded by scientific observations" (Margot, 2011b, p.100). The objectives of forensic science were thought of as important means for intelligence and investigation, even if not explicitly defined in such terms. Forensic science is a scientific endeavour, which is concerned with "applying science and scientific reasoning to criminal and civil investigations" (De Forest, 1999, p.197), and needs to be understood as a science itself, with its own reasoning schemes. However, the current prevailing understanding of forensic science (or rather 'forensic sciences' or 'forensics', see Roux et al. (2012) and Margot (2011a)), with its trend towards increasing specialisation and 'single trace view' (Ribaux et al., 2015b, p.63), progressively replaced the initial generalist perspective (DeHaan, 2008). In this depiction, forensic science is viewed as the mere application of various scientific techniques to assist the criminal justice system. It is denied a scientific basis on its own, but is rather conceived as relying on the application of a patchwork of fundamental sciences (Ribaux, 2014).

Forensic science, the study of crime, views the trace as an information vector at the service of intelligence in order to understand criminal phenomena, reconstruct criminal cases, and link crimes. “[Clues] are used as ‘forensic intelligence’, in other words as information used to further direct ongoing criminal investigation and disruptions, rather than as props in the dramaturgy of a criminal trial” (Williams, 2007, p.780). This consideration of forensic science leads to a shift in the perception of the purpose and role of forensic science, from a mainly judicially oriented to a broader intelligence-led framework (Ribaux et al., 2010b), and influences the processing of traces and the decisions made in the investigation process as well as the roles taken by the different parties involved in this criminal justice system. This ‘new’ interpretation might be viewed as a return back to the roots of forensic science (Ribaux et al., 2015b).

The definition of forensic science goes hand in hand with its integration model in the processes of the criminal justice system, the procedural structure and organisation. The organisational structure between providers of services of forensic science and police organisations varies across different countries and institutions. Differing modes of integration of science into the law enforcement institutions exist. To understand these different models, Williams (2007) proposes the distinction between the so-called ‘structural’ and ‘procedural’ interpretations of scientific integration with the distinctions between ‘assistants’ and ‘experts’ respectively. This view has already been expressed by Fraser (2000) when he drew the distinction between ‘scientific support’ and ‘forensic investigations’.

‘Structural’ integration, for its part, is overlapping with the current prevailing understanding of ‘forensics’ (see Table 2.1 on page 12). Forensic science is kept apart from the actual investigation and the responsibilities of the crime scene and trace processing lie mainly in the hands of the police. Both parties, police and scientists, seem to be uninformed entities in the same and shared investigation process. This view is reinforced by one of the recommendations given by the National Research Council in the NAS report (National Academy of Sciences, 2009) to increase the much debated scientificity of forensic science. This recommendation supports the ‘structural’ integration model and proposes the separation of forensic science *laboratories* from law enforcement agencies.[1] Forensic science personnel, and the perception of their roles, are still largely considered separate from the police (Ludwig et al., 2012). The scientist is not supposed to be involved in the investigation or in the elaboration of the hypothesis regarding the events or the combination of the information retrieved from other traces in the case (Risinger, 2013).

Whereas in the 'procedural' integration model, the emphasis lies on the supporting quality of forensic science and "the distinctive knowledge-based expertise" of forensic scientists is acknowledged (Williams, 2007, p.772). This second approach recognises the added value of aware and informed decision-making by equal and acknowledged partners and suggests an integrated system (Fraser, 2007). In the same sense, Kind (1987) identifies that specialised chemists or biologist can not contribute effectively to the crime investigation, if "they know nothing about the problem they are supposed to solve" (Ribaux et al., 2015b, p.63).

Most of these studies deal with the anglo-saxon system, or more precisely with the British system. In particular, the roles and responsibilities of the actors in the system change depending on the system at hand. In Switzerland, the study area, a generalist approach is followed with a 'procedural' integration of forensic science and forensic scientists in the criminal justice system. Crime scene investigators, a mix between fully trained forensic scientists and police officers trained in all branches of forensic science, are involved in the criminal procedure from the start, i.e. the crime scene investigation. A collaborative basis exists between police investigators, crime scene investigators and the prosecutor's office (see Chapter 3), encompassing good communication between all parties.

2.2 Object of forensic science

Traces are ephemeral remnants of past events, whose causes remain to be clarified (Margot, 2011a). They are vectors of information that is not directly intelligible or seizable, which needs to be perceived and considered in the context of an event, often a litigious action under investigation (referred to in general terms as the case) (Margot, 2014). Hypotheses about these past events, serving the reconstruction of the sequence of events, can be structured on the basis of these signs, with variable

[1] The terminology used highlights the separation of forensic science (enclosed in laboratories) and law enforcement agencies.

degrees of reliability and certainty. The *clue*, the information retrieved from the trace, "feeds different processes of the criminal justice system and even beyond, e.g. gathering intelligence for the police inquiry, supporting the structuring of evidence for court decisions, or revealing the structure of repetitive criminal activities" (Delémont et al., 2014, p.1756). Margot (2014) distinguishes an additional state between *trace* and *clue*, which is the *sign*. The *trace* becomes *sign* when it is recognised as such and related to a story, however, its signification may still remain obscure. This *sign* becomes *clue* when this signification is delivered, an element of knowledge explaining the story with a certain degree of power (see Chapter 5 for more details). The final state of this same object – *evidence* – is considered by the judge for court purposes (Hazard and Margot, 2014).

The understanding and definition of forensic science differ in regard to their object of focus. The fragmentation approach, according to the 'structural' integration model, centres around judicial issues and comprehends the use of forensic science mainly for court purposes. In this perspective, forensic science's main purpose is the provision of evidence for court. In this sense, the 'structural' integration model, with forensic science confined to the laboratories, is prone to limit the use of the trace and thus the utility of the clues (Ribaux, 2014; Laurin, 2013; Rudin and Inman, 2013).

The generalist approach, however, puts the trace itself in its centre, with its study being the object of forensic science. By 1963, Kirk had already noted that the focus of forensic science should be on theory and principles, instead of technology and laboratory processes, and even more recently, various authors have emphasised the need for research in this area (Crispino et al., 2011; Margot, 2011a,b; Stauffer, 2011).[2]

> Forensic science has an object: the study of crime and its traces. These are silent witnesses that need to be detected, seen, and understood to make reasonable inferences about criminal phenomena, investigation and to be used for intelligence, investigation and court purposes. After all, traces are the most elementary information that result from crime. (Margot, 2011b, p.100)

[2] "In short, there exists in the field of criminalistics a serious deficiency in basic theory and principles, as contrasted with the large assortment of effective technical procedures." Kirk, P.L., *The Ontogeny of Criminalistics.* The Journal of Criminal Law, Criminology and Police Science 54 (1963) 235.

The object of forensic science is the study of crime and its traces. In the 20th century, Locard emphasised the fact that any action or rather contact generates physical traces as well as their exchange.[3] Considering this principle of transfer by Edmond Locard (1920) and the explanatory asset of divisible matter formulated by Inman and Rudin (2002), it follows that every action, the criminal action being one of them, creates a more or less important amount of physical traces depending on the intensity of the action (Crispino, 2006). In addition to their legal definition, the intensity (e.g. violence) applied to the action may potentially allow us to distinguish the legitimate from the criminal action. It is one of the investigator's tasks to detect traces, decipher them and differentiate between the ones related to the criminal action and the ones not being a "remnant of unlawful activity" (Roux et al., 2012, p.8)(e.g. background or contaminations; relevant and irrelevant traces, see Chapter 5). However, many scientists and detectives decide after analysis that a trace can be considered as such because it matches the suspect, not at the beginning of the investigation. Typically, investigators and analysts define the environment of the suspect and then look for traces that match that environment, rather than looking at the circumstances of the crime and crime scene to determine the traces (Stoney, 1984).

2.3 Roles of forensic science

Corresponding to differentiated needs imposed by the structural and procedural constraints, by the definition or object of forensic science, forensic scientists assume several different roles (see Table 2.1). The roles and competences of the forensic scientist diverge depending on the integration model chosen by institutions or organisations (Williams, 2007), and from crime scene to court, become increasingly restricted (Delémont et al., 2014). Three steps can be distinguished: (1) the investigation is conducted, relevant information is found, while developing hypotheses, investigating scenes, detecting and collecting traces, (2) the structuring of the information and (3) the consideration of the traces in the light of competing hypotheses of interest, with the role of the forensic scientist focussed on the presentation of the value of evidence (Ribaux et al., 2010b). In addition, the criminal

[3] "La vérité est que nul ne peut agir avec l'intensité que suppose l'action criminelle sans laisser des marques multiples de son passage. [...]. Les indices dont je veux montrer ici l'emploi sont de deux ordres: Tantôt le malfaiteur a laissé sur les lieux les marques de son passage, tantôt, par une action inverse, il a emporté sur son corps ou sur ses vêtements les indices de son séjour ou de son geste." Locard, E. (1920). *L'enquête criminelle et les méthodes scientifiques*. Chapter 4. Flammarion, Paris.

phenomenon needs to be understood and the related information integrated into the investigative process. This understanding of the roles equates to the 'procedural' integration model described by Williams (2007). The insufficiency of knowledge on the side of the service users in order to offer informed assessments of the quality and the investigative potential of forensic science is remedied through this 'expert collaboration' approach, which recognises and acknowledges the utility of expert knowledge.

> The effective employment of resources at crime scenes is dependent on the reciprocal knowledge of investigative personnel as well as the differences in perceived roles and responsibilities. Reciprocal knowledge is knowledge that is not restricted to an individual's own specific role (e.g. prosecutor, investigator, forensic specialist) but also sufficient knowledge about other people's roles involved in an investigation in order to understand how to collaborate productively (Ludwig et al., 2012, p.58).

In the 'structural' integration approach, practitioners "are seen as having strictly delimited areas of competence and are required to provide technically reliable and valid information to be evaluated by other crime investigators" (Williams, 2007, p.771). The responsibility and decision-making power lie in the hands of those "with a more central stake in crime investigation and detection" (Williams, 2007, p.772), under whose direction and supervision the forensic work, or more precisely, the technical forensic work, is carried out. This dissociation of the roles is accompanied by an implicit hierarchy established between the investigator and the scientist.

Forensic science is epitomised as the analysis of the trace and the interpretation of the results. In this context, the principles from an intelligence-led policing practice seem to have no room and their integration would thus be impossible (Ribaux et al., 2015b). Nonetheless, forensic intelligence, defined as "accurate, timely and useful product of logically processing forensic case data" (Ribaux et al., 2003, p.50), developed silently within several police organisations (e.g. National Crime Faculty). Forensic intelligence must be recognised as an integral part of forensic science, and as such, represents also one of the roles and one of the contributions of forensic science.

The misjudgment of this role, as described above, reinforces the distance between the forensic scientist and the investigation in order to "keep independence that is supposed to promote their impartiality in the perspective of the trial process" (Delémont et al., 2014, p.1760). The debate between the fragmentation *versus* generalist approach of forensic science in the criminal justice process is also fuelled by the discussion about contextual bias. A group of researchers argues that context bias, created by the integration of forensic science in the criminal justice process affects the results of their examinations and thus, forensic scientists should operate without any context information (e.g. Dror and Cole, 2010). Often, this argument is brought forward in favour of the separation of police and 'identification bureaux'. However, this is not the separation discussed here. That there might be people (e.g. technicians) completely shielded from the case circumstances may eventually be desirable (although not necessarily possible), however, the decision as to what is used, and in which way, should be made by informed investigators, both police and forensic. The non consideration of context information is solely possible for decisions on selective, well defined operations (often techniques), but not for decisions about the use of traces or their analysis (De Forest, 1999). Then, context information is not only desirable but necessary in order to make useful choices (Association of Chief Police Officers, 2006). Indeed, in evaluative studies, the collaborative approach was recognised as being favourable of effective forensic science (Adderley et al., 2007; Bradbury and Feist, 2005; Rossy and Ribaux, 2014).

2.4 Synthesis

Forensic science starts at the crime scene, with the crime scene investigation leading to the search, detection, recognition and collection of traces. While this first application of forensic science is often performed either by crime scene technicians or police officers, the problems related to "the search and collection of traces on a crime scene calls for much wider competencies than solely technical skills" (Delémont et al., 2014, p.1757). Forensic scientists, specifically forensic generalists, need to be included in this process because they have a broad knowledge of the information potential of traces contributing to the investigation. In this perspective, the objective of forensic science is to gather intelligence from traces through the application of a set of scientific methods to help the criminal justice system in general but also in a broader context, the general security (see Table 2.1). Depending on whether the definition follows the generalist approach or the patchwork of disciplines one, the role and usefulness of the traces are different.

Tab. 2.1.: Summary of elements of 'forensics' vs forensic science.

	'Forensics'	Forensic Science
Integration model	Structural	Procedural
Definition	Patchwork of scientific disciplines applied to issues of the court	Generalist
Object	Evidence for court	Trace
Role	'Assistant'	'Expert'
Hierarchy	Subordinated / restricted to lab	Equal partners
Information access	Restricted	Informed partners

When considering the intelligence-led policing model (Ribaux et al., 2003, 2010b; Morelato et al., 2014; Raymond and Julian, 2015; Rossy and Ribaux, 2014), or the convergence of forensic science and criminological concerns (Ribaux et al., 2015a), the integration of forensic science needs to be rethought. The application of forensic intelligence, being an integral part of forensic science, demands a completely integrated and informed partnership between all actors involved in the criminal investigation and trace processing in order to support decision-making and processes on different levels of security (e.g. strategic, operational and tactical levels).

Forensic science has the ambition to have a more proactive position in the inquiry, and more generally regarding security issues. The reconstruction of the criminal event, through the interpretation of traces, requires knowledge of traces and their information potential, their transfer and persistence characteristics, which only the forensic scientist can contribute (Ribaux, 2014). The starting point to consider is the crime scene, which determines the quality and nature of the information through the collection of traces (Martin et al., 2010; Crispino, 2008; De Forest, 1999). This step needs a systematic processing, from general to particular, founded on a scientific basis (Crispino, 2006). The quality of this crime scene investigation conditions the information available in the inquiry and later on at the judicial step.

The focus needs to be on the quality of the information of the clue, with all its variations in utility dimension, instead of being on the laboratory processes or solely the judicial contribution of forensic science.

3 Criminal Justice System and its Actors

Forensic science is embedded in a security and judicial framework, however, in the scope of this study, the focus is set on the judicial dimension. In this chapter, the moments in which forensic science is used and who is responsible at these different moments in the judicial proceedings are clarified. At these different stages, different actors with differing responsibilities are intervening, involving different objectives and striving for different answers or goals. Thus, forensic science is used in the perspective of different aims. In addition, the question of who decides involves also a financial aspect. Depending on the person or entity in charge, a different budget will be used.

The judicial system is different depending on the country under scrutiny, thus, the focus is put on the Swiss criminal procedure. A comparison with the adversarial system is made, as the majority of studies in the field originate from anglo-saxon countries.

The decision-making process described below is more generally valid and is, thus, transferable to a wider range of countries. In all criminal justice systems, similar decision-making needs to be gone through, involving triaging traces and thus their attrition at each stage.

3.1 The criminal procedure

The criminal investigation process is regulated by the Swiss Criminal Procedure Code (hereafter CrimPC, relevant excerpts can be found in Appendix A).[1] According to Article 10 CrimPC, "Every person is presumed to be innocent until they have been convicted in a judgment that is final and legally binding".[2] Switzerland is a

[1] RS 312.0 Code de procédure pénale suisse du 5 octobre 2007.
[2] Official version in French: "Toute personne est présumée innocente tant qu'elle n'est pas condamnée par un jugement entré en force."

mixed system of prosecution, combining inquisitorial and accusatorial elements. The preliminary proceedings mostly respect the inquisitorial system (non adversarial, written and secret), while the accusatorial system prevails at the trial stage (oral, adversarial, and public) (Gilliéron, 2014). In order to uphold the presumption of innocence and to protect the suspect from the public eye, the investigation is not public. Based on the results of the investigation, the prosecutor shall bring charges, in written form, if the grounds for suspicion are considered to be sufficient (Article 324 CrimPC). The criminal trials are oral, public and conducted by the judge who asks questions in order to find the material truth (Gilliéron, 2014).

Briefly, in an inquisitorial system, "the criminal justice authorities shall investigate ex officio all the circumstances relevant to the assessment of the criminal act and the accused. They shall investigate the incriminating and exculpating circumstances with equal care"(Article 6 CrimPC).[3] The goal of the prosecution is not to seek a conviction but rather to discover the truth and to apply the law. Whereas in an adversarial system, the duty of the judge is to ensure the fair play of due process, whereas the responsibility in seeking the truth of the case relies on the defence and prosecution. The parties act independently and are responsible to investigate the case in order to present their evidence before a passive and neutral judge or jury that will decide on guilt (Gilliéron, 2013). In a simplified way, the adversarial principle can be characterised by the search for 'proof', rather than the 'truth' in the inquisitorial system (Sanders and Young, 2012). In both legal systems, the police operates according to both objectives, which is reflected in the way police make use or perceive the usefulness of forensic science to their case (see Chapter 4).

3.1.1 Prosecution authorities

In the Swiss criminal enquiry, a common agreement and collaboration exist between the public prosecutor and the police, which regulate and shape the roles of each of them (Article 307 CrimPC). Enquiries are begun by the police, and the investigation is opened by the public prosecutor (Article 300 CrimPC), who is in charge of collecting all evidence, incriminating and exculpatory (Article 6 para 2 CrimPC). The public prosecutor is in charge of deciding whether to open an investigation and gives instruction to the police (Article 16 CrimPC); enquiries can be begun by the

[3] Official version in French: "Les autorités pénales recherchent d'office tous les faits pertinents pour la qualification de l'acte et le jugement du prévenu."

police themselves (Article 15 para 2 CrimPC). The preliminary proceedings comprise the police enquiry (Article 299 CrimPC). During this phase, the police works autonomously, at the exception of the cases for which the public prosecutor gave instructions, to "establish the facts relevant to an offence" (Article 306 CrimPC).[4] Once the police enquiry has been conducted, the police establishes a report on the performed measures and the obtained results for the public prosecutor. The public prosecutor can then decide whether to open an investigation (Article 309 CrimPC). The objectives of the investigation by the public prosecutor are to 'clarify the factual and legal aspects of the case" (Article 308 CrimPC).[5] During the preliminary proceedings, the public prosecutor acts as prosecution and police surveillance authority. The public prosecutor is the 'leader of the proceedings', holding the responsibility of the inquiry and thus, needs to be informed of the all the actions performed by the police in this phase. Both, the police enquiry and the investigation by the public prosecutor form the preliminary proceedings (Article 300 CrimPC).

The public prosecutor has all powers of prosecution and investigation in his hands: the public prosecutor monitors and coordinates the work of the police during the pre-investigation and investigation phases. Regarding forensic science, formally, the decisions made regarding traces, whether it is the collection or the analysis, lies with the prosecutor's responsibility. However, the duties of the police in the police enquiry comprise the securing and evaluation of forensic and other evidence (Article 306 CrimPC). The prosecutor occupies a mainly supervising role and leaves the decisions regarding traces and their collection and analysis with the police (crime scene investigators). However, the public prosecutor can order additional analyses, or enquiries of the police, after the investigation has been opened (Article 312 CrimPC). In practice, the analyses of traces might be performed during the police enquiry, at the request of the police. However, when a hit is yielded, thus identifying a suspect, the public prosecutor will be informed and an investigation is opened.

3.1.2 Police organisation in the canton Vaud

In the canton Vaud, the main police agency under scrutiny in this study (PolCantVD) disposes of the *Service d'Identité Judiciaire* (forensic unit, hereafter ID) which is part

[4] Official version in French: "Lors de ses investigations, la police établit les faits constitutifs de l'infraction."

[5] Official version in French: "Le ministère public établit durant l'instruction l'état de fait et l'appréciation juridique du cas de telle sorte qu'il puisse mettre un terme à la procédure préliminaire."

of the judiciary police. The crime scene investigators are responsible for investigating the scene of crime, collecting and analysing traces (e.g. fingermarks) or submitting them to an external laboratory for analysis (e.g. biological traces), interpreting the results and communicating with police investigators and crime analysts, and reporting to the public prosecutor's office. In addition, for certain types of crimes, they delegate the collection of transportable objects to police first responders who can be requested bring them to the laboratory of ID.

The police investigation is carried out by *police investigators of the Judiciary Unit*, at the exception of those carried out by the *Gendarmerie*. These services work in close collaboration and report to the public prosecutor's office.

The forensic intelligence unit, *Brigade d'appui, d'analyse et de coordination (hereafter BAAC)*, delivers weekly reports on highlighted case series based on modus operandi and spatiotemporal similarities of the cases. During the study phase (January to May 2015), daily morning reunions were organised between crime scene investigators and a member of the BAAC, mutually updating each other about the currently operating series, or modus operandi to be vigilant about.

3.2 The decision-making process

As previously stated, the criminal justice system and especially the legal framework it is embedded in, are different across countries. However, some decision steps remain the same across differing judicial systems.

The crime scene is the starting point of the criminal investigation process (Martin et al., 2010; Schuliar, 2009; Crispino, 2008; De Forest, 1999), which conditions the quality and nature of information through the collection of traces. The criminal investigation process was formalised by Kind (1994) and Brodeur (2005) into two complementary models. The latter differentiates three steps, with a focus on the investigative phase: the identification of the suspect, the localisation of the suspect and the structuring of the evidence. The former distinguishes three 'chapters' based on their underlying inferential reasoning: (1) the problem to find, (2) the refinement, checking and preparation for trial, and finally, (3) the problem to prove. In the first 'chapter', a mainly abductive reasoning approach is applied, starting from the traces leading to the suspect(s). Whereas, once a suspect is apprehended, the reasoning changes to a deductive inference, from the case to explain the occurrence of particular traces. These 'chapters' showcase the different ways in which traces can be used and pave the way to the manifold roles of forensic science in the investigation process (Delémont et al., 2014).

Complementary to the models defined by Kind (1987) and Brodeur (2005), we propose to adopt a perspective based on the practice of forensic science within the investigation process as a decision-making process. Several decision-making steps can be distinguished, which are however not completely linear but rather closely linked or even intertwined. These following decision-making steps should be recognised:

1. the decision to attend the crime scene,
2. the decision to search for traces,
3. the decision to collect traces,
4. the decision to analyse traces,
5. the decision to use traces in the inquiry,
6. the decision to collate trace-related information in a structured database,
7. the decision to use traces in court.

3.2.1 The decision to attend the crime scene

Prior to the search for traces, the question regarding the attendance of the crime scene by a crime scene investigator needs to be answered. This first triaging step, more often than not latent triaging step, conditions the further process. Crime scenes that are not attended can not be source of traces, and thus, clues or evidence (Baylon, 2012; Ribaux et al., 2010b). However, as mentioned earlier, for some crime scenes of minor importance, crime scene investigators decide to not perform an investigation themselves, but ask police first responders to collect objects and deliver them to the laboratory of the ID. This happens for cases of minor importance and when no visible traces can be observed. Although no crime scene investigation as such is performed, these cases remain in the process.

A model proposed by Ribaux et al. (2010a) suggests four dimensions of knowledge when it comes to crime scene processing (from the decision to attend the crime scene to the collection of traces): the *strategic*, *criminal*, *immediate* and *physical* dimensions can be influential when deciding to attend and how to search a crime scene.

The *strategic* dimension "is constituted by the organisation, available resources in terms of available technology and knowledge, a set of management rules, priorities and strategies devised by the management following an intelligence-led philosophy" (Ribaux et al., 2010a, p.68).

The *criminal* dimension is the knowledge about "the current structure of the criminality and about current criminogenic hot-spots" (Ribaux et al., 2010a, p.69). As stated earlier at the PolCantVD, the BAAC and the crime scene investigators meet regularly to update each other on the prevailing cases and their modus operandi. Indeed, this information also guides the decision to investigate a crime scene. The case on its own might potentially not be considered important enough to dispatch a member of the crime scene unit to investigate. However, knowing that similar cases (either by modus operandi or spatiotemporal characteristics) have been committed in the near past renders the case more important due to its potential affiliation to a known series. The consideration of crime intelligence in the decision to attend a crime scene was also demonstrated by Resnikoff et al. (2015), performing a survey-based study questioning the crime scene investigators about their use of criminal knowledge in case and trace processing.

The *immediate* dimension is composed by the circumstances of the case. For example, in burglary cases, this would correspond to answering the following questions: When did the theft occur, in the evening, at dawn, or during the night? How were the buildings accessed? What was their modus operandi? What kind of objects were stolen? All of these questions belong to the intellectual reasoning of hypothetical reconstruction of the possible sets of actions from known information and observation.

Finally, the *physical* dimension refers to the trace itself and its matrix (i.e. the base), in due consideration of its tendencies of transfer during the crime and persistence until its detection by the forensic or police staff. These elements characterise the existence of the trace. In addition, the physical aspects of the trace might need the application of revelation techniques for it to be detected.

3.2.2 The decision to search for traces

The criminal investigation continues with the problem to 'find', or rather, the search for traces. To 'find' is subjected to the search for traces, and has an insinuation of hazard. However, the investigation is active in its nature, and the result depends on what one is looking for. The search for traces needs to be systematic and based on observational skills. In addition, a broad understanding of the criminal and immediate environments as well as the traces is required (Delémont et al., 2012, 2014). This decision step involves triaging: the traces that are not known will not be looked for and similarly those that are not looked for, can not be detected, collected nor analysed. Hence, limiting the search for traces, but also the training of crime scene investigators to only certain types of traces leads to the exclusion of other types of traces from the investigation process.

In some police services, priority is put on 'rich' biological traces (e.g. blood, saliva, semen, *versus* 'contact' traces) to be sent to the laboratory for analysis for burglary cases (Mapes et al., 2015). Hence, it can be assumed that the crime scene investigators stop paying attention to other types of biological traces and focus on finding only this type, limiting thus the set of traces to be collected and analysed.

The search for traces results at best in their detection, which includes the crucial capability of recognising traces as such. While this is easily conceivable for visible traces, such as certain fingermarks and shoe marks, biological traces, especially contact traces can often not be made visible at the crime scene. This is why the concept of detection of traces needs to be understood in a wider sense, as the 'imagination' of possible traces at specific locations due to the scenario or the presence of other traces, which is based on a hypothetical-deductive reasoning process (Fann, 1970). The recognition, anticipation, and detection of traces do not involve conscious decision-making and are thus not decision steps as such. However, they are conditioned by the same factors influencing other decision steps, such as cognitive abilities linked to personal skills, training and experience.

The factors, influencing this step, can be separated into three categories according to Hazard and Margot (2014) (see also Hazard (2014)): human (the knowledge), structural (the organisation, strategy, resources) and contextual (the type of encountered situations). Compared to the model proposed by Ribaux et al. (2010a), in Hazard's model, the human dimension is added (which is also discussed above regarding the detection of traces), whereas the contextual dimension comprises the situational and physical dimensions described above. In addition, the criminal dimension was determined to be of importance for the decision to search for traces (Resnikoff et al., 2015; Ribaux et al., 2010a).

3.2.3 The decision to collect traces

Once traces have been seen and recognised, the decision of collection is made. Material considerations as well as cognitive aspects need to be taken into account in this decision. Material elements include components such as the quality of the trace and the availability of the technological resources. The cognitive aspects include a retrospective dimension (the knowledge traces and their collection techniques) as well as a "prospective orientation of the scene examiner to a set of likely investigative and evidential trajectories to which these artefacts may become decisive – or at least relevant" (Williams, 2007, p.763) (see also Hazard (2014)).

This filtering step concludes the crime scene investigation. Indeed, one can hardly go back to the crime scene at a later point. Knowing that, this triaging step might be applied in a less strict way. At a later stage, the set of available traces might be enriched by traces that are recovered from the suspect, who might be identified, localised and apprehended later in the criminal investigation.

3.2.4 The decision to analyse traces

In the next step, the question of whether a trace is analysed or not is examined. This decision affects the traces that are processed in-house (e.g. shoe marks, fingermarks) as well as the traces that are submitted to external laboratories for analysis (mainly biological traces). Several end-to-end studies do not consider this step as a decision-step on its own, but merge it with the decision to collect traces (ANZPAA-NIFS, 2013; Home Office, 2007). Only once traces have been submitted to the laboratory, the attrition rate between traces submitted for analysis and those actually analysed is assessed. This means that all collected traces would be submitted for analysis, and that, at the laboratory, other people decide, probably upon technical questions, if all traces are to be analysed. Hence, following their reasoning, one could consider this decision as being obsolete, since the collection step serves already as triaging step and the reason for collection is that it will be analysed and further exploited. While this might be true to a certain extent and for some traces, the decision to analyse a trace is rather anticipated to the moment of collection of traces. Hence, the decision to analyse a trace is still made, however, the moment of decision-making is merely shifted to the moment of collection of traces. Nonetheless, in many cases, more traces are collected than analysed, and in particular, not all traces are analysed in the first instance or at the same time. Hence, a decision is made regarding the traces to be analysed and the traces to be analysed first.

The factors to take into account in the decision to use traces that must be submitted to an external laboratory are not the same as the ones for the in-house analysed traces. Indeed, this is a budgetary issue. Albeit, traces that are analysed in-house may also incur costs (time and personal resources), the traces that are submitted for analysis to an external laboratory incur additional costs subtracted from a specific, (often) limited budget. This is why these traces involve a more severe triaging. Indeed, fingerprints, being analysed in-house, are more restrictively collected (e.g. in terms of quality) as practically 100% of the collected traces are processed further (see Table 6.3).

The decision to analyse a trace, being the central element of this study, will be further discussed throughout this study. It is proposed that this decision is not only based on the knowledge dimensions suggested by Ribaux et al. (2010a), but also on the utility dimension, by extending their model to the question under scrutiny (see Table 6.4). Utility of the clue is defined as added value in terms of information to the case. Thus, the anticipation of the potential utility of the clue (expected utility) could guide the decision to analyse a trace. In this sense, traces are used in a variety of situations/perspectives, showcasing a broad range of differing dimensions of utility (see Chapter 5).

This decision-making step is the last gatekeeping step before traces or – rather the information retrieved from traces – can potentially contribute to the inquiry and beyond. Hence, the choice of which traces to analyse is important as it is the premise for the range of information potentially available. In a context of limited resources, this decision gets increasingly attention. While it is difficult to justify leaving traces at the crime scene, as one can hardly return to the crime scene processing, making a selection of the traces to analyse is that more important.

3.2.5 The decision to use traces in the inquiry

The decision to use a trace in the investigation, or rather a clue – the information gained through the analysis of the trace – is closely linked to the decision to analyse a trace. As stated previously, it is assumed that the anticipation of the use of a clue in the investigation guides the decision to analyse traces, or even to collect traces.

Furthermore, this decision can be seen as closely intertwined with the decision to use traces in court. However, some traces are used solely for intelligence purposes, whether it be for creating investigative links or finding other traces (Ribaux et al., 2015b). Whereas others are mostly analysed with the anticipation of its use in court.

An example of the use of traces in the inquiry is the use of shoe marks, which reveals the information of the shoe brand. This information can thus be added to the suspect profile searched for by police officers. In addition, this type of trace is often used solely for crime linking purposes (Hazard, 2014).

Another example would be the use of forensic information in interrogations. A famous case is the one of convicted murderer and rapist Russell Williams, who confesses to murder charges after being presented allegedly incriminating shoe marks found on the crime scene during his interrogations.[6] This example showcases the utility of the clue as leverage in interrogations or catalyst of confessions.

3.2.6 The decision to collate trace-related information in a structured database

Then follows the decision to collate trace-related information in a structured memory in order to use the potential of this information for intelligence on criminal phenomena, repetitive crimes, etc. This exploitation can be performed in a reactive as well as proactive approach. The shift from a mainly reactive approach, by supporting and reinforcing crime investigation, to a proactive approach, "to focus strategies,

[6] see https://www.youtube.com/watch?v=4Ewq44BjK28

operations and tactics, and to support decision-making processes at every level of the organisation" demands a new understanding of forensic science, with the integration of forensic intelligence (Ribaux et al., 2015b, p.65). This step can also be evaluated based on usefulness, and cost/benefit ratios (De Ceuster et al., 2012). Indeed, the nature of the crimes and the related traces influence the probability of creating links.

This decision can only be favourable if a culture of forensic intelligence is adopted regarding forensic science (Raymond and Julian, 2015). The focus needs to switch from the sole evidential value of traces for court outcomes towards its use in generating "timely knowledge aiming to support information processes and decision-making in policing and in the broader security context (e.g. strategic, operational and tactical levels)" (Morelato et al., 2014, p.181). In this proactive approach, the detection of crime is not the sole utility dimension, but the focus is also the broader security context (e.g crime prevention).

This structured database can vary in scope; it can be locally organised or fed by international partners. Depending on the reach and the formalities of inclusion (only traces, only persons, only convicted, also suspects, etc), the probability of obtaining a hit varies. Again, criminological aspects of the type of crime with the according traces need to be taken into account, when constructing these databases, i.e. is the type of crime serial, if so, crossing borders, and so on. In Switzerland, situational aspects of modus operandi of different kinds of serial offences have been introduced in the PICAR (Plateforme d'Information du CICOP (Concept Intercantonal de Coordination Opérationnelle et Préventive, Intercantonal concept for operational and preventive coordination) pour l'Analyse et le Renseignement) database, allowing a general depiction of the offences committed in several Swiss cantons (Birrer, 2010; Rossy et al., 2013).

3.2.7 The decision to use traces in court

The final step of the use of forensic science in the criminal justice process consists in its use for court purposes. The clues are not necessarily the same as the ones that were used in the investigation. In the investigative phase, the evidential value of the clues does not need to be as high as when it comes to court (e.g. links created by shoe marks). The difference in the amount of validation required to get an analysis admitted in court vs. the requirements for its use as an investigative aid might be substantial.

This decision is not necessarily subsequent to the previous decision, but can also intervene right after the decision to use a trace in the enquiry. Fibres for instance will be used in the enquiry and might be used in court, but no database exists recording all clothing material, at least not in an intelligence perspective.

3.3 Synthesis

The decision to analyse a trace is embedded in the above described judicial framework and decision-making process. Understanding how this decision is made through determining which factors are involved in the decision to analyse a trace is the second main objective of this study and will be detailed in chapter 6.

These decision steps are not completely linear, as highlighted in Figure 3.1. The first five are indeed subsequent to another: a trace can only be searched for if a crime scene was attended, it can only be collected if it was searched, it can only be analysed when it has been collected, and similarly, it can only be used in the inquiry if it has been analysed. However, traces that have been analysed and are used in the inquiry can be collated in database and/or used in court. For instance, shoe marks that have been found at a crime scene, collected and analysed, can be used in the inquiry to include the shoe brand in the offender description. In addition, this information will be recorded in a structured database, with other information regarding the pattern of the shoe mark. However, this information will not necessarily be used in court, as other evidence might have stronger evidential value to the case. Fibres for instance will be used in the inquiry and might be used in court to tie the link between the suspect and the victim, but no introduction of this information into a database will be performed. Some traces might even only be used in the inquiry through their introduction into a structured database, however, the decision to use in the inquiry will probably be made before the decision to collate in a database. In this case, the use of the database is merely the means to render possible the use of the trace in the inquiry. When considering the strategic implications of the use of trace-related information in a database, other purposes than just for the current inquiry, are conceivable, like, for instance, preventive measures. However, in this

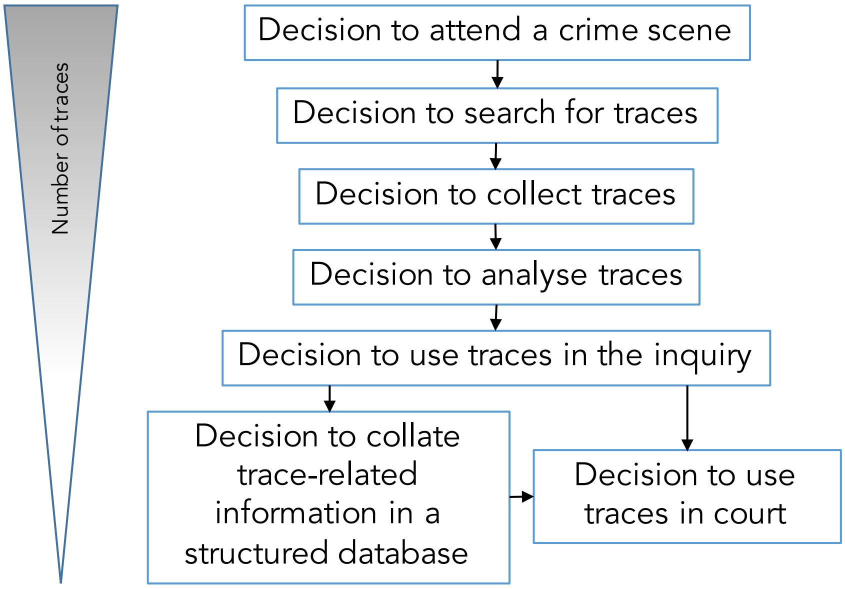

Fig. 3.1.: Representation of the decision steps and their sequence. The number of traces decreases when following the decision steps down the chart, limiting thus their implication and their possible contribution.

case, we exit the criminal justice process and enter a wider general security and policing framework.

The linearity of the first five decision-steps can however be interrupted by the decision to not attend the crime scene by the crime scene investigators, but to instruct the police first responders to collect objects and deliver them to the laboratory for further analysis. In this situation, police officers not specialised in forensic science attend the crime scene and search for transportable objects potentially bearing traces, which are then collected and analysed by the crime scene investigators.

On the one side, one must notice that the triaging at early stages is influencing the following steps, as they depend on the previous ones. However, the decisions need to be made in a conscious, logical manner. For instance, the potential of the DNA database to link crimes or to identify suspects is null if the trace is not analysed (for instance due to a lack of suspect). Naturally, if a trace analysis yields a negative result, then again the comparison with the profiles in the DNA database can not be performed. On the other side, the anticipation of the use of the trace in an intelligence perspective, or as evidence for court, can guide the decision to analyse a trace. Thus, the triaging step influences the investigation but the way in which the investigation is conducted also influences the triaging step.

It is important to distinguish the different phases regarding the questions of *When* a trace is analysed and *Who* is responsible at that particular moment. Therefore, the different actors of the judicial system are specified in this chapter. As the knowledge of the case, but also of forensic science and its possible application scopes, of the different actors hugely differ, it needs to be taken into consideration when assessing the decision to analyse a trace. The financial aspect might also play a role, as the shift in responsibility of the case is accompanied by a shift in financial resources and responsibility. The budget is different depending on the canton and, in addition, the cost for a DNA analysis varies among external laboratories (Pitteloud, 2014).

The question of When? The integration of forensic science in the whole investigation process needs to be taken into account. The chapters defined by Kind (1994) and also the different stages described by Brodeur (2005) help determining *When* and *Why* traces are used. A first assumption can be stated as follows: the question *When* traces are used is directly related to the question *Why*, and thus the perception of their potential utility to the case. If traces are used as means of last resort, it will most probably show in the results of the question *When*. Likewise, this applies when considering the assumption that traces or rather their information are used to 'build a case against a suspect', which would lead to the use of clues only when a suspect has been identified. So, the question of *When* will be considered in regards to events or actions, such as the identification of a suspect or the use of other investigation techniques.

"First the charge then the evidence" (Kind, 1987, p.10) was Kind's view of the court process. The suspect is considered guilty and proof is needed, looked for and used to assess (often corroborate) this hypothesis. This is largely a deductive process. "The idea that the evidence may gradually built up during the trial process to the point where it inexorably points to the guilt of the accused is only partly true, inasmuch the guilt of the suspect has already been hypothesised" (Kind, 1987, p.10). The suspect has thus already been identified and the story is aligned in order to match the implication of the suspect. Clues should however be used in an unbiased, reconstruction of events approach (Barclay, 2009), following the abductive reasoning process described by Kwan (1977).

The connection between *When* and *Why* leads to the consideration, that there are reasons for use that are incompatible with moments of the investigation. For instance, in order to find corroborative proof that a specific suspect committed the crime, one needs to have a suspect in the first place. In like manner, this is the case when we wish to exclude a suspect.

The question of Who? As mentioned before, forensic science is about more than the application of scientific disciplines to criminal cases in order to assist the court. The role of the forensic science is linked to the question *Why* traces are used, and its role multiplies through the different uses of the traces. In the evaluative phase, the result of the analysis of a trace is evaluated in the light of a set of hypotheses (such as the prosecution hypothesis and the defence hypothesis). Whereas in the investigative phase, the relation between the information (obtained by the result of such an analysis) and the case (or one question of the case) is more uncertain. These relationships are supposed to be investigative leads and do not need to withstand the same rules applicable for evidence presented in court. It is mainly the framework of use which permits the flexibility and the possibilities of use.

The question of *Who* also involves all the actors of the investigation and criminal justice process, i.e. police and scientific investigators, scientists and prosecutors. It is important to recognise the structure of the institutions and their collaboration framework to understand the distribution of competencies and authorities. This involves the distinction made by Williams (2007) of the ‘structural’ and ‘procedural’ integration framework for forensic science in the investigation. The responsibilities and limitations of the different actors shift depending on the framework in place.

The investigation is carried out by the police, under the supervision of the public prosecutor. For minor crimes or as long as no suspect has been identified, the police handles the case by themselves. In serious offences, the case is ‘handed over’ to the prosecutor’s office, and hence, the state’s budget is accessed instead of using the police service’s financial budget for the analyses. Hence, the structure of the investigation as well as the financial resources accessed influence *Who* makes the decision.

4 Performance Measurement Indicators

Albeit the decision to analyse a trace has never been explicitly studied, it is often indirectly assessed through the study of the use or non use of forensic science by police or in court in order to allegedly evaluate the performance of forensic science. First, we will take a look at *police use* of forensic science, with studies starting as early as 1963 up until recently. These studies give an insight in the types of traces used, who was in charge of the decision to use them, when and why these traces were mainly exploited. In order to determine the success of the strategy in place, the *impact of traces on case clearance* and the predictive power of forensic science for the progression of the case at judicial stages (arrest, charge, conviction) will be outlined and discussed. These studies being contradictory but mostly negative, the *unanalysed traces* will be considered to see if potential information could be gained through their analysis. Finally, since the current use of traces does not seem to include all the information potential of the clues, the *change in use of traces* as proposed in literature will be subject to scrutiny.

4.1 Police use of forensic science

In early studies, it becomes clear that the use of forensic science is consistently low (Parker, 1963; Greenwood et al., 1975; Eck, 1983), even if variable between different police forces (McCulloch, 1996). This infrequent use was also noted by Schroeder and White (2009), who studied the use and utility of biological samples in homicide cases from 1996 to 2003. The Pathfinder Project (Burrows et al., 2005) and the DNA Expansion Programme (Home Office, 2005), both tried to influence exactly this problem. However, their conclusions were contradictory, with one stating that an increased use was influencing the number of identifications and the other one stating that the increase did not have an effect on case outcomes.

As the infrequent use was perceived as being problematic, several reasons were proposed, including the lack of knowledge of police investigators when it comes to the potential value or utility of forensic science to their case (Eck, 1983; Ramsay, 1987; Horvath and Meesig, 1996; Tilley and Ford, 1996; Barclay, 2009). This can be comprehensible in the late 1980s or the early 1990s, however, even Barclay comes to that same conclusion in 2009, that is more surprising considering the large publicity of forensic science and the infatuation with biological traces.

However, this lack of knowledge might not have the same reasons this time around. Inadequate communication might be at the core of the problem (Ramsay, 1987). The infrequent use is caused by the lack of awareness of the available techniques on the side of the police, and the lack of awareness of the available traces on the part of the scientists. This 'knowledge gap' seems to be enhanced by the 'structural' integration of forensic science in the investigation (i.e. dissociating forensic science from police), described by Williams (2007) and outlined in the second chapter. An extreme picture that could be drawn is that scientists, separated from police investigation, have to analyse what police investigators tell them to. Hence, the decision to use traces with all the dimensions involved in this decision (which traces, when and why to use) lies with police investigators only.

As a consequence of this lack of knowledge the use of traces is quite restrained. As it could be shown here, 'building a case against a suspect' was a recurrent reason for using (collecting, submitting and analysing) traces (Ramsay, 1987; Horvath and Meesig, 1996), which, in an adversarial system, is not surprising and corresponds to what is asked of the police. Similarly, when no suspect had been apprehended, no or less traces were collected, submitted or analysed (Baskin and Sommers, 2010). This clearly shows that the utility of forensic science is mostly seen for the judicial phase of the criminal process. Obviously, this underestimates the utility of clues and their potential information in the investigative phase or to draw links with other cases perpetrated by the same offender. The use of traces as means of last resort is one example of the limited use of forensic science by police investigators (Burrows and Tarling, 2004; Schroeder and White, 2009), which might be explained by the lack of communication and knowledge.

In addition, frequencies of use of forensic science were shown to depend on the seriousness of the offence (Baskin and Sommers, 2010, 2011; Wilson-Kovacs, 2014). In 97% of homicide cases, physical traces were collected and an equally high percentage of physical traces were submitted for analysis (88%) (Baskin and Sommers, 2010). In contrast, in 30% of assault and robbery cases traces were collected, and in only about 10% of cases these traces were examined (Baskin and Sommers, 2011).

In the so-called end-to-end studies (Home Office, 2007; ANZPAA-NIFS, 2013; Mapes et al., 2015; Brown et al., 2014; Bradbury and Feist, 2005), a similar strategy to measure the performance of crime scene investigation is adapted than in the early studies. These studies consider the entirety of the judicial process, enabling the assessment of the use of the trace at different steps. Similar metrics are employed in order to quantify the work of the investigators, such as the timeliness and number of crime scene investigation, analysis submission, and reporting. In addition to the number of traces collected and analysed, the number of hits with databases is introduced as a supplementary factor. However, due to the disparity of the results, no clear view could be obtained. These variations occur at all levels: crime scene attendance, collection and analysis of traces, introduction of the results in the database.

These deceiving results are not surprising, and as emphasised by Ribaux (2014), these studies reveal several elements of discussion. The first is the decision-making process and its influence on the functioning of the process and its results. All of the decision steps influence the number of traces available at a later stage. Secondly, the focus on court is highlighted with the efforts being on increasing the number of traces available in court and the preliminary work performed is sometimes neglected.

4.2 Factors affecting case clearance

Another approach to allegedly measure the impact of forensic science on the criminal justice process, consists in its prediction power for judicial steps (arrest, referral, charging, conviction). Again, the focus and restriction on court matters are obvious, thus limiting the results regarding the usefulness of forensic science. Similar to the previously discussed indicators, the emphasis on judicial steps, without acknowledging the previous triaging steps and reasons is prone to limit and bias the view on forensic science in the criminal justice process.

Several studies examined the influence of traces on case clearance. The results were contradictory: the presence of traces was a predictor for arrest (Peterson et al., 2013), whereas in another study no influence on any of the stages of the process (arrest, referral, charging, conviction) could be noted (Baskin and Sommers, 2010; Ingemann-Hansen et al., 2008). However, the significance of the prediction for arrest remains unclear, as it appeared to be the mere presence of traces that had an impact on arrest (without being analysed or used). As seen earlier in the decision process, the presence of traces can be put on the same level as the search for and collection of traces. Logically speaking, a fingerprint will not point towards a person without being analysed and compared to records in a database. However, these last two steps were not taken into account in the study.

When considering solely biological traces in homicide cases, the results showed that biological traces presented by prosecutors acted as the most important predictor of cases reaching court (Briody, 2004). In regard to guilty pleas, the seriousness of the charge was the most important variable. There was no significant association between biological traces and guilty pleas. When biological traces were presented, juries were more likely to convict.

In robbery and burglary cases, traces are a strong indicator for conviction once a suspect is arrested (Feeney et al., 1983). Furthermore, witness identification of a suspect seemed to play a major role in predicting conviction. Interestingly, a difference was noted in the effect of a particular trace between different locations.

Other factors seem to be involved in this relation, such as case characteristics. An interesting result was that most robberies went unsolved due to a lack of witnesses (Baskin and Sommers, 2011). Hence, case circumstances and police strategies (in finding and questioning witnesses) seem to be the most influential factor regarding the clearance of robbery cases (see also Wilson-Kovacs (2014)). Similarly, in homicide cases, traces were not an indicator for case clearance but rather police actions: the location of witnesses, notifying the homicide unit and securing the area appeared to play a role for the processing of homicide incidents (Wellford and Cronin, 2000). In the same line, police investigation techniques were more powerful predictors of arrest than forensic science (Keel et al., 2009). However, a significant relationship was found between database searches and arrest. This is contrary to the results found by Baskin and Sommers (2010) where database search results and 'hits' were quite limited and not predictive of arrest or any other criminal processing outcome.

In addition to the behaviour and actions of the police, the attitude adopted by the offenders after the crime and during the police investigation was singled out in an extensive study about homicide clearance and its variables (Mucchielli, 2006). The clearance rate for homicide in 2000 in France was at about 80%. Two thirds of the cases were solved practically immediately due to the attitude of the offenders (e.g. they announced themselves to the police or were caught in the act). In 20% of the remaining cases, the crime was committed without any witnesses and the offenders tried to continue their life as if nothing had happened. In only 7% of cases, material traces collected from crime scenes were the crucial element leading to the author(s). The determining role of these traces was emphasised, noting that physical traces had played only a secondary role in other cases. The author further stated that physical traces were getting a value once the scenario had been established, so their role would be again indirect. This would confirm the essential but not determinative role of the work on the crime scene.

Questioning the utility of forensic science in the criminal investigation, Brodeur (2005) separated the classical investigation in three different categories: (1) inquiry of identification, (2) inquiry of localisation and (3) structuring of evidence in order to determine the factors that help the resolution of homicide cases (e.g. identification or arrest of a suspect). His results are then also separated into these categories, for the time of resolution and the factors influencing it. As with Mucchielli, Brodeur found that 80% of homicide cases are solved and again in 80% of these cases, a suspect is identified within 24 hours. In 55% of solved cases, the suspect is localised in the same period of time. This led to the hypothesis that uniformed police men, who were the first to be present when a homicide was announced, played a crucial role in the clearance of homicide cases (same result as Greenwood et al. in 1975). Indeed, this was confirmed by the data: 32% of suspects were first questioned by the uniformed police officers, who arrested 38% of suspects. In general, human sources (e.g. witnesses, police officers) were the number one factor influencing the clearance rate. Having said that, physical traces were used in less than 2% of case investigations for suspect identification. Similar results were obtained for the localisation of the suspect(s). In summary, it was stated that the role of scientific evidence in case resolution was more than secondary. Forensic expertise appears as rarely crucial for case resolution. In addition, it was noted that in the majority of cases, it was not the collection of knowledge that led to the clearance of the case, but rather the rapidity of intervention. Paradoxically, in the unsolved cases, knowledge needs to be collected, but did not lead to the clearance of the case. Then again, the utility dimensions of physical traces are more diverse than the simple identification. Similarly to what was suggested regarding the infrequent use of forensic science, these results have to be considered in the context of the period of time in which the data were collected and analysed (1990–2001). As the use of traces was quite low, it is not surprising that their influence was low, too.

In their studies, Baskin and Sommers (2010, 2011) used the exact same data as in the report they co-authored (Peterson et al., 2010), but found contradictory results. In the recently published report by Peterson et al. (2013), the authors attempt to explain these discrepancies. They re-examined the effect of traces on case processing using again the same dataset. This time, they used an alternative analytical approach. Instead of analysing the data per type of case, they analysed the data in aggregate form while controlling for offence seriousness and study site. They believe that "combining these data reflect a more generalised, systems perspective that investigates the role of traces (of any type) on case processing outcomes" (Peterson et al., 2013, p.82). The descriptive and bivariate analysis, as well as the multivariate analysis results indicate that traces are statistically related to several case processing outcomes. The influence of traces appears to be time- and examination-dependent. The collection of crime scene samples was a significant predictor for arrest and referral to the prosecutor. The examination of traces predicted case referral, charging, trial conviction, and severity of sentences. Guilty pleas do not appear to be influenced by clues. The results also suggest that, while most traces go unexamined, the mere presence of traces is associated with arrest and the movement of cases through the justice process. Indeed, this was the case in the Russell Williams case, where an unanalysed shoe mark was used during the interrogations as catalyst of confessions. The explanation they give is that due to the expected utility of the collected (but unexamined) traces and the investigators' experience, they would anticipate informative test results. As such, traces would provide "momentum to their cases, providing corroboration and additional support with investigator theories and other existing evidence, or even supplying the missing piece to a puzzle as to how the crime likely unfolded" (Peterson et al., 2013, p.89). Crime linking through clues did not affect conviction outcomes because it was present in only a small percentage of cases reaching that stage. However, successfully linking the suspect to the victim and/or crime scene appeared to affect trial outcomes and to increase sentence lengths for homicide cases – cases in which physical traces were most frequently present.

Peterson et al. (2013) stated that the analysis of data aggregated for different types of crimes is an improvement compared to their previous report (Peterson et al., 2010) and the studies by Baskin and Sommers (2010, 2011). Surely the total number of cases and thus the number of traces will be higher. Taking into account case attrition through the criminal justice process, it is useful if the initial number of cases is high. However, the nuances are lost by merging the data together (less informative) but the results seem to be more robust. While it appears to be the mere presence of traces (with examination taking place after arrest) being predictive for arrest, the question is whether the traces are only collected once a suspect is apprehended (direct arrest (e.g. Baskin and Sommers, 2011)). Thus, traces are collected in order to 'build the case against the suspect'. This would also mean that if no suspect were immediately found, investigators do not see the need to collect traces for progression of the case. Furthermore, different types of traces were merged for this study. It was shown by Bond (2007) that this is an important factor when considering the conversion of a DNA 'match' to a detection. In general, the results and conclusions drawn seem to be more influenced by the analytical technique than by the data. In addition, underlying, not determined factors seem to play a role for case development and outcome. Thus, the reliability of the variables chosen needs to be reconsidered as well as the choice of variables. Some of these studies considered the *presence of traces* to be influential on (at least) one stage of case outcomes, however without going into detail about the traces, in terms of nature of the trace, location (and hence pertinence) and also their expected utility.

In the article *Value of DNA Evidence in Detecting Crime*, Bond (2007) examined the percentage of DNA 'matches' that were converted to *detections*, in regards with the type of biological traces (blood, cigarette end, saliva, chewing gum and cellular biological traces), their location (in or outside the scene) and the experience of the investigator and the Crime Scene Examiner (CSE; accredited or not).[1] The most important influence on the DNA 'match' outcomes was the experience of the investigator (no accreditation leading to a decrease in detections) in burglary (residential, commercial) and vehicle theft cases. Whereas the experience of the CSE did not affect the conversion at all (analogously to Roman et al. (2008), who found that who collected the traces was of no influence on case processing). Blood

[1] It must be noted that here the understanding of *detection* is the charging of the suspect after a DNA 'match' with the suspect's profile was found and he had the possibility to explain the presence of his DNA on the crime scene, but the police did not accept the explanation or the suspect confessed to the crime. Whereas in their paper from 2008, Bond and Hammond (2008) substituted the term 'detected' with 'solved', with the same definition mentioned above.

traces producing biological traces were the most stable, the less affected by all the predictors. A possible reason could be that it was less straightforward for the suspect to give an explanation for the legitimate presence of his blood on the crime scene. The study by Bond (2007) showed that, when measuring the impact of biological traces, it is important to consider the types of traces and their location. In addition to these material features, another key factor was the 'experience and accreditation' of the investigating police officer (not that of the crime scene examiner). For officers with 'investigating accreditation' (at least four years of service), the likelihood of converting a DNA match into a detection was significantly greater than for those without such accreditation. This was true for cases involving other DNA sources than blood (where the evidential value is incontestably significant). One possible reason for these differences is the way in which the biological traces are introduced into the questioning of the suspects.

A more qualitative approach was added to a first quantitative part of the study, by assessing the order between arrest and obtained result in homicide cases (McEwen and Regoeczi, 2015). Indeed, of 135 cleared cases with probative results of trace analysis, in only 17% of cases (23), these results were obtained prior to arrest. Justifications provided include the amount of time needed for trace analysis and the high percentage of quickly resolved cases. To the author's knowledge, this is the first study of its kind to recognise the importance of not only the analysis of traces (versus the mere presence of traces), and the result of these traces, but also the knowledge of these test results prior to arrest, in order to assess the prediction power of traces for this event. Logically, only the knowledge of the probative test result could potentially influence the case progression. As discussed earlier, the mere presence of traces does not deliver any information to the investigators and thus can not help the investigation.

4.3 The unanalysed traces

By looking at the number of unanalysed traces in a case, researchers try to assess the efficiency of laboratory services, however, the results are often extrapolated to the usefulness of forensic science in general. Most of the studies were performed in the United States of America, where laboratory backlog constitutes a big problem to case processing, leading to time delays between submission of traces for analysis and reporting of multiple months (Horvath and Meesig, 1996; Lovrich et al., 2004; Pratt et al., 2006; Mennell and Shaw, 2006; Schroeder and White, 2009; Strom and Hickman, 2010). A qualitative approach is adopted by either looking at the reasons for the non submission for analysis, or, by assessing the potential information gain through the analysis of these unanalysed traces.

For unsolved homicide and rape cases from 1982 to 2003, in roughly half of the cases, biological traces were collected but not analysed (Pratt et al., 2006). The main reason for not submitting biological traces to laboratories was that no suspect had been identified (31%, see also Lovrich et al. (2004)) or that it was not considered a primary investigative tool for law enforcement agents (50% of respondents, see Pratt et al. (2006)). Other law enforcement survey respondents reported a suspect had been identified but not charged or that testing had not been requested by the prosecutor. The surveyed agencies identified funding as a constraint in submitting biological traces to laboratories. Finally, crime laboratory workload, personnel and funding issues were identified as factors for not submitting traces. Another reason was the lack of awareness of the existence of the national DNA database (Pratt et al., 2006).

The estimates of unsolved cases in these two studies ranged from 1982 to 2003. It was only in 1986, that DNA analysis was used for the first time in a criminal case (Wong et al., 1987). This would mean that, of course, in none of the cases from 1982 to (at least) 1986, DNA analysis could have been considered a primary investigative tool. A similar argumentation can be applied to the lack of awareness of the national DNA database (and the insecurity about the usefulness of this trace in the case), as the national DNA database was only established in 1994 (Lovrich et al., 2004). As the proportion of unsolved cases in the early phase of the study period remains unknown, we can not deduce if those reasons mentioned are also applicable to the later years, where DNA analysis was available and the national DNA database had been established. Although one has to keep in mind the state of the national database in its early years of existence in terms of number of profiles registered and types of profiles registered (only for major crimes, only convicted suspects).

In a further study to assess the possible barriers in submitting traces for analysis, data from 2003 to 2007 were used (Strom and Hickman, 2010). The results showed that approximately 14% of all the unsolved homicide cases, 18% of the unsolved rape cases and 23% of the unsolved property crime cases contained traces that had

Tab. 4.1.: Factors inhibiting the submission of traces to crime laboratories reproduced from Strom and Hickman (2010, p.394).

Inhibitory factors	Percentage of agencies
Suspect has not been identified	44
Suspect adjudicated without forensic evidence testing	24
Other/not applicable	24
Case has been dismissed	19
Uncertain of usefulness of forensic evidence	17
Analysis not requested by prosecutors	15
Suspect has been identified but not formally charged	12
Inability of laboratory to produce timely results	11
Insufficient funding for analysis of evidence	9
Laboratory will not accept forensic evidence due to backlog	6
Uncertain where to send forensic evidence for analysis	2

not been submitted to a laboratory. The reasons indicated by the agencies for not submitting traces to laboratories can be found in Table 4.1.

Scientific analysis is not requested due to a significant backlog and case priority is given according to the date of the court process. However, when no suspect has been identified, no court date has been set which lowers the priority of analysis. One must keep in mind that for some types of traces, the analysis only makes sense when a comparison sample is available. As such, the failure to submit traces for analysis can also be related to this problem, and not only, as stipulated in the article, be a consequence of a lack of awareness of the investigators. It is important to differentiate between the various types of traces in order to appreciate their utility and understand their use by the investigators. We might actually postulate the exact opposite hypothesis: investigators are aware and understand the utility of biological traces and their limitations (especially in terms of backlog and priority), and hence, do not request testing when no suspect is available. This also depends on the structure of the DNA database in the United States. One interesting aspect would be to compare this use of biological traces, which need to be submitted to an external laboratory to traces analysed in-house, such as is often the case with fingerprints. For the traces submitted to an external laboratory, the factors cost and timeliness should play a predominant role. The finding that 24% of the agencies did not submit traces for analysis when the suspect has been adjudicated without forensic testing is noteworthy, as these findings concern unsolved crimes, these adjudications would have been acquittals. Without further detail on this matter, no other interpretation can be made. However, it was noted that 17% of the agencies were uncertain regarding the usefulness of traces and hence did not submit them for analysis. It needs to be clarified if this is, indeed, an uncertainty in the sense of a lack of knowledge of the potential of traces in the case in question, or if it relates to the appreciation of the utility of the clue.

Emphasis needs to put on the fact that the results given by Strom and Hickman (2010) (and also Pratt et al. (2006)) represent the percentages of questioned agencies. Breaking this same information down to the case level or even the trace level, would add a whole new vision. In the scope of this study, the expected utility of the not analysed traces is examined.

In a follow-up study (Nelson et al., 2013), an update is provided on the status of DNA backlogs in the United States by the National Institute of Justice. Efficiency of laboratory techniques continues to grow with increasing automation. However, backlogs continue to increase as well and solutions proposed to reduce backlogs include hiring additional DNA analysts, further automate work processes, implement new technologies. Thus, only business practices or technological advancements are proposed as remedies to control the wave of requests for DNA analysis, no emphasis is put on the quality of the trace submitted for analysis, let alone the potential utility of the clue to the case. This view reinforces the argument about the problems with the definition of forensic science and its performance, which highlights the relevance of this work.

One must distinguish the backlogs in crime laboratories from the untested traces awaiting submission, stored at the police department (Ritter, 2013). Indeed, some traces might not be useful to the case: "In cases where consent is an issue (the suspect admits sexual contact but maintains it was consensual), detectives may consider that the SAK [Sexual Assault Kit] does not add any important information to the investigation" (Ritter, 2013, p.40). Even if one would consider a trace to be potentially useful, often results from sexual assault kits are unavailable during the investigation (Menaker et al., 2016).

Several law enforcement agents believe that the only use of forensic science is to tie a particular suspect to a case, and without a suspect, forensic science can not aid the criminal investigation (Beaver, 2010; Wilson-Kovacs, 2014). This view restricts the utility of forensic science. By using DNA databases, more unsolved cases would receive new leads and new suspects and traces would then speak for themselves. Several law enforcement agencies demonstrated a limited perceived utility of forensic science. The increased use of DNA database could lead to more suspects as more intelligence can potentially be gained through their use. However, traces never speak for themselves. They need to be interpreted in the context of the case.

Another approach that was suggested consists of measuring the number of fingermark impressions that are currently not recovered or considered for examination, and assessing “the usefulness of these impressions in terms of the number of additional detections that would result from their examination” (Neumann et al., 2011, p.32). The results showed that the examiners did not recover a certain amount of potential fingerprints. “However, the data also demonstrate that the approximately 3600 additional fragmentary impressions recovered by the research team did not lead to the production of a significant number of additional pieces of evidence (38 potential additional evidence)” (Neumann et al., 2011, p.45). However, it must be clarified that there is a number of protocols in place “to filter out less useful fingerprint impressions” (Neumann et al., 2011, p.45). This means that a judgement of the quality takes place before the collection of the trace, and hence, if this is well done, only a few pertinent impressions will be missed. This triaging strategy is only possible for visible traces, contrarily to biological traces where often contact traces were inferred and presumably recovered.

4.4 The changing use of forensic science

Most studies that can be found in the literature that deal with performance of forensics were performed in anglo-saxon countries, in an adversarial system. Most anglo-saxon countries focus on numerical indicators when it comes to measuring the performance of forensics (application of science to matters of the court). They assess measurable factors such as the number of crime scene investigations handled by investigator or the number of collected traces per crime scene, or the timeliness of these distinct ‘milestones’ in the investigation. Instead of acknowledging that these initial decision-making steps influence the use and thus the usefulness of forensic science, most performance measurement indicators focus on quantitatively assessing one step of the process. The assessment of one siloed decision-making step or technical throughput is prone to undermine the actual usefulness of forensic science in the criminal justice process, and especially in the investigation. This particular approach, the measurement of the number of performed analyses highlights the misunderstanding of forensic science, as purely technical support, as forensic science is reduced to the delivery of technical services.

In an attempt to grasp the contribution of forensic science in the criminal justice process, a number of studies introduced some form of performance indicator. However, most of these indicators suffer from different weaknesses, from the definition of forensic science itself to problems of reliability and validity (Williams and Weetman, 2013). In early studies, police use of forensic science was scrutinised in terms of number of scenes visited, number of traces collected and number of traces submitted by scene of crime officers. Albeit variable between different police forces (McCulloch, 1996), the use of forensic science was found to be consistently low (Home Office, 2005; Burrows et al., 2005; ANZPAA-NIFS, 2013; Brown et al., 2014).

Another way of attempting to measure the contribution of forensic science, in particular in conjunction with the development of databases, is by looking at the possible increase in the number of identifications, i.e. the number of hits in the database (Burrows et al., 2005). While this factor appears to be pertinent at first, especially when comparing to the invested resources (e.g. number of scenes visited), it constitutes an oversimplified approach to measure the value of forensic science. From the decision to send a crime scene investigator to a scene, to the identification of a suspect by traces, multiple decisions need to be made: which scenes are investigated by the crime scene investigator, which traces searched for and how, which traces are collected, which traces are analysed, which techniques are used in the laboratory to analyse the traces, are the results compared to references, what are the number and the types of available references (size and structure of the databases), etc. When considering the aforementioned ratio, the distinction between the different decision steps is lost. A unique metric is used by confounding different effectiveness indicators for different stages of the decision-making process.

In addition, these indicators focus on one unique dimension of the contribution of forensic science, the identification of a person. Other dimensions, such as the exclusion power or the reconstruction of events, are neglected (see Chapter 5).

In order to measure the effectiveness of forensic science, some authors considered the predictive power of trace processing on case outcomes. Although the proportion of submitted traces was close to 100% for homicide cases, their influence on any of the milestones of the judicial process (arrest, referral, charging, conviction) remained ambiguous/undefined; two groups of authors working with the same dataset obtained differing results and reached diverging conclusions (Baskin and Sommers, 2011; Peterson et al., 2010). Hence, the results and conclusions seem to be more influenced by the methodological concerns than driven by the data itself. Other factors, such as case characteristics, seem to be involved in case clearance.

4.5 Synthesis

In summary, in the mentioned evaluative studies, forensic science is depicted as having only a limited utility and that its value lies mostly in court issues. These results of the utility of forensic science need however to be nuanced; when recognising all variations of its purposes and its integration in a common investigation procedure, forensic science can contribute in manifold manners and have a substantial impact on the criminal justice process and beyond (Ribaux, 2014).

The change in perspective modifies the expectations regarding forensic science. Rather than being based on the routine use of specialised techniques centred on the production of evidence for court, the actual inquiry and its parameters need to be taken into account when assessing the results of the use of forensic science (see section 3.2). Depending on whether intelligence, investigative or evaluative processes are followed, the perception of the quality of forensic operations at different stages differs (Delémont et al., 2014).

The majority of these studies considered a ‘structural’ integration framework when it comes to the relation between forensic science and police investigation, focussing on econometrical indicators to measure the contribution of forensic science to the criminal justice system. These indicators mostly concentrate on assessing technological efficiency or the impact of forensic science on judicial issues, instead of focussing on the investigation and the trace itself. This (deliberate) separation of the actors needs to be taken into account when studying the decision to analyse a trace, as it affects the structure of and communication within the working relationship between these two fields.

Traces need to be considered in a coordinated action to increase their value, in close collaboration between forensic scientists and investigators (Roux et al., 2014).

In addition, the focus when measuring their value needs to shift away from the overemphasis on identification, but rather, their potential to reconstruct events and find answers to the question of 'what happened?' (Robertson and Roux, 2010). For this to be possible, one needs to consider the human factor, which are highly qualified crime scene investigators that need to carry out the work. Julian et al. (2011) determined the skills and attributes to be an effective crime scene examiner/officer. They identified seven skill set attributes, including a knowledge base ("having a holistic understanding of where CSI fits into the criminal justice process" (Kelty and Julian, 2010, p.41)) and communication skills. Both of these factors were previously described as lacking in the evaluative studies (see also (Ludwig et al., 2012; Ludwig and Fraser, 2014)). Similarly, Evans and Kebbell (2011) determined the set of characteristics of an effective analyst, and considered the position that the analyst should not be viewed as a simple technician, but rather, as an associate to the decision-maker, with problem-solving capabilities. As the same problem is also applicable to the crime analysts – a new field in the police environment – and not only the crime scene investigators, it is even more wide-ranging and general. There is a discrepancy between the education of the police and their need of technical competencies, often viewed as a technical addition.

5

Influencing knowledge dimensions

The relationship between the forensic scientist and the criminal justice system is complex, and thus, assessing the contribution of forensic science to this system is challenging (Roux et al., 2014; Wilson et al., 2010; Julian et al., 2011; Kelty et al., 2015). In order to be able to measure the utility, it is necessary to determine the expectations of the contribution of forensic science to the criminal justice system. This problem will be approached by the introduction of the concept of utility, more precisely, utility of the clue in the investigation. First, the known framework surrounding the use of forensic science in the crime scene processing will be emphasised. Then, the concept of utility will be presented and discussed through different examples.

5.1 Existing knowledge dimensions

When trying to *translate* the model proposed by Ribaux et al. (2010a) to the decision to analyse a trace, the four proposed dimensions can help establish a working framework (see subsection 3.2.1). However, a readjustment or redefinition of what is included in the different dimensions (without claiming exhaustivity) was performed and is outlined below (see Table 6.4 for detailed explanations):

strategic type of intervention, prosecutor in charge of the case, team of crime scene investigators in charge, number of collected biological traces;

immediate type of target, surveillance camera, witness report, armed robbery, violence against the victim, number of offenders, number of collected shoe marks, number of collected fingermarks;

physical type of biological trace, presumptive testing performed, matrix of the trace;

criminal knowledge of crime link.

The number of collected biological traces was categorised in the strategic dimension, as it was noted that in cases considered less important, like burglary cases, only 1 or 2 biological traces were collected. This factor thus constitutes a strategic choice in relation to the perceived seriousness of the case.

These dimensions can be seen as a set of constraints and facilitators for the use or non use of a trace. It can be hypothesised that different relations exist between the different decision dimensions outlined earlier (the questions of when and who, the understanding of forensic science, and the integration model) and these four knowledge dimensions.

5.2 Utility dimension

Commonly efficiency ('doing things right') or effectiveness ('doing the right thing') are indicators used for performance measurement in business (Neely, 1998; Bourne et al., 2003). However, a combination of both ('doing the right thing right') corresponds to what we are really looking for (De Forest, 1999). Being efficient without considering if what we are doing is the right thing, or, being effective without considering the means invested, are both equally useless. This brings us to *utility*, a concept that has long been used in decision theory in economy (Marshall, 1920; von Mises, 1998).

Before adapting this concept to the context of forensic science, the difference between the notions of trace, sign, clue, intelligence and evidence used in this study needs to be recollected (see Chapter 2). The definition of utility used in this study is based on Soergel's definition (Soergel, 1994) and updated according to some details provided by Stock and Stock (2013).

5.2.1 Relevance, Pertinence, Utility

An entity is considered topically relevant for a question, when there is a relationship connecting both the entity and the question, and, the entity sheds light on the latter. It is considered pertinent, if it is "relevant and if it is appropriate for the person, that is, if the person can understand the document and apply the information gained.

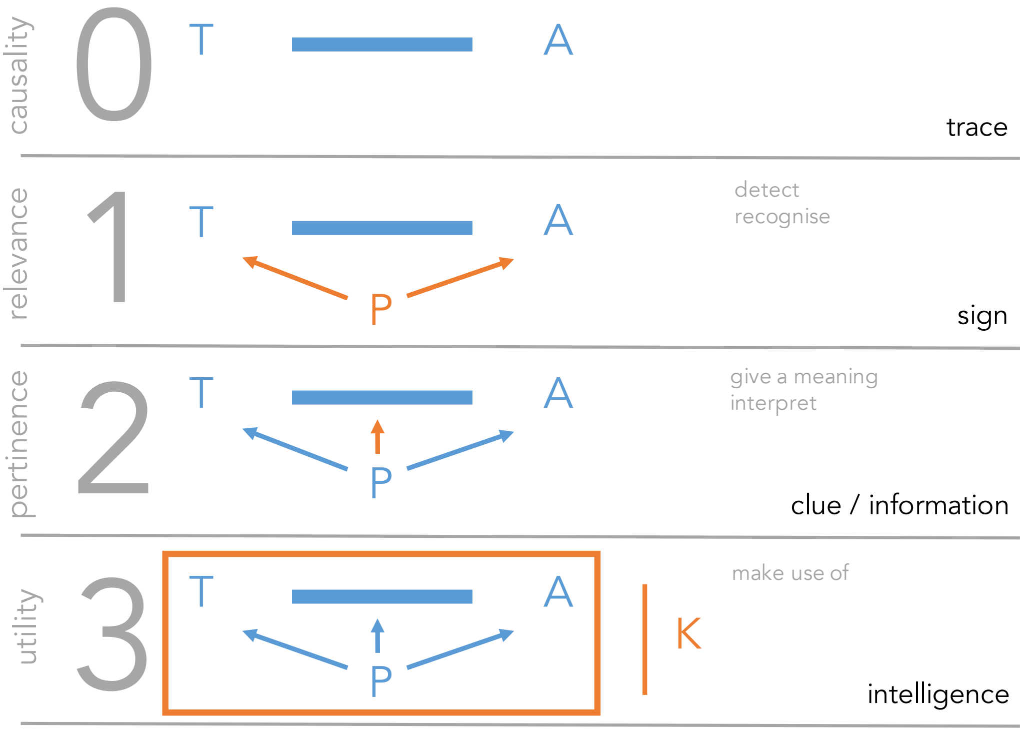

Fig. 5.1.: Representation of the concepts of relevance, pertinence and utility. Simultaneously, the passage from trace, to sign, clue/information and intelligence. Initially, only two entities are present: the trace (T) and the activity (A). In the first step, the person (P) or user is introduced and assesses the two entities. In the second step, the user assesses the link, and finally, utility is assessed in the light of the knowledge (K) already available.

[...] An entity has utility if it is pertinent and makes a useful contribution beyond what the user knew already" (see Soergel, 1994, p.590).

The schema in Figure 5.1 highlights the different steps. Initially, the trace (T) and the activity (A) are linked. The trace is the result of an activity; which might be of interest in the investigation or originate from events associated with the location. The trace is material, it exists independently of all signification. It is an incomplete remnant of past events, not belonging to the common environment of the location where it is found. It contains information of its source and of the activity through which it was produced (Margot, 2014).

When a causal link exists, the trace becomes relevant to the activity. A trace is considered relevant to the activity if it is related to the activity, and, can in principle, be exploited further. Relevance to the activity is user-independent (Stock and Stock, 2013), i.e. a trace can be relevant solely to the activity. Furthermore, relevance is binary, either a trace is relevant or it is not.

In the first step, the person (P) detects and recognises the trace as such. If this trace is considered to be relevant to the person (P), the trace is inferred to be a sign. This time, the consideration of relevance to the person is not black and white, but builds up gradually depending on several elements; the location of the trace, the knowledge of previous activities at that location, and so on, influence the evaluation of relevance of a trace.

In the second step, the person (P) assesses the trace, the activity and the link with the activity, and gives a meaning to and interprets the link connecting the trace and the activity. The information extracted from the sign reveals its signification and becomes a clue, of which the pertinence can be evaluated. The information conveyed by the sign needs to be understood by its user and be linked to the activity in order to be pertinent. The sign changes to clue or information. The pertinence of the sign depends thus on the relevance of the trace to the activity and the person, its quality and the expertise (knowledge of traces and their analysis) of its user. A sign – a trace considered to be relevant – when delivering no useable information because of low quality can not be considered pertinent. The assessment of the pertinence of the sign by the user is influenced by context information and the knowledge of the user. The possible causes for the traces are inferred, to which the case reconstruction is adapted.

Three conditions need to be fulfilled for a clue to be considered useful and become intelligence. In analogy to the definition of utility by Soergel (1994), (1) the trace has to be related to the activity in question, (2) the sign must be understood by its user and (3) the clue has to shed light on a question in the case, without being redundant. The clue is considered intelligence if it adds new and valuable information to the case, which contributes to the processing of the case. Especially the second part is of importance: the mere novelty of an information is not sufficient in order to contribute meaningfully to the case. For instance, processing a fingermark to confirm the identity of an offender whose identity had already been uncovered through the analysis of a biological trace is redundant when considering solely the identification purpose of both traces. However, this same trace can contribute to the reconstruction of events (e.g. the direction of a fingermark on an object, thus indicating how it was held), and thus, the appreciation of the utility is dependent on the question that is asked. Utility is assessed in regards of the knowledge (K) already available in the case. This highlights the dependance with the knowledge previously available in the case. In addition, it depends on the information potential of the sign itself. The information gained from the sign needs to add value to the case for it to be considered useful and become intelligence. In other words, the information gained needs to matter; the question that needs to be answered is: does it make a difference if the trace or the information conveyed by the trace would be absent? The knowledge base needs to be affected by the gain in information provided by the clue. Hence, the purpose of confirmation can also be considered useful, if the degree of certainty regarding the initial hypothesis (about the source or the activity) was modified due to the attainment of the information.

5.2.2 Utility and the dimensions of utility

Forensic science can feed multiple channels and its utility depends on the information we expect to retrieve from. Drug residues found in wastewater can provide an overview of consumption habits of different types of drugs in a non-invasive way and over a long period of time (Been et al., 2016). This use of forensic science is made in a public health perspective and can lead to more focussed policing and preventive actions.

In the criminal justice process, the dimensions of utility of forensic science are more diverse than the provision of evidence in court. For major crimes, the most important contribution of forensic science is given in the investigation, where the uses include (Barclay, 2009, p.345):

- "clarify the sequence of events;
- identify critical facts;
- provide elimination factors;
- direct lines of enquiry such as targeting the house-to-house interviews;
- assist in interview strategies or crime scene strategies;
- prioritise and assist lines of enquiry".

These can be taken as a starting point in order to categorise the main reasons for use, regarding the information that wants to be retrieved from it. Some of these can be considered to be too vague ('identify critical facts'), and can be interpreted variably: from the determination of the qualification of the case, the implication of the different offenders to the identification of the suspect. Another use made of situational traces is for profiling reasons, in order to infer the behavioural traits of the offender (Fox and Farrington, 2015), feeding the criminological knowledge about offenders of certain types of cases.

The utility of the clue is very versatile and dependent on different factors. The main and most obvious dimension of utility is, of course, identification of a suspect. Although, it can be important to consider also the intelligence component of information or the reconstruction of the micro-sequence of events (Barclay, 2009; Ribaux et al., 2006), these facets are often neglected. One example of this utility dimension is for the provision of intelligence: "In addition [to be decisive or at least relevant], even where such artefacts are assumed not be usable for the construction of a case against an actual or potential suspect for a particular crime, scene examiners still have to consider whether or not their construction and analysis may contribute to the collation of police intelligence relevant to current or future investigations of other crimes" (Williams, 2007, pp.763–764). In the same line, Tilley and Townsley (2009) suggested an 'organic' integration model, emphasising the optimal contributions of forensic science as the "reduction of volume crime, the quick elimination of the innocent and the conviction of the guilty" which need to be reached by "understanding and managing the human, social side of the forensic process" (Tilley and Townsley, 2009, p.376). The decision-making process, the actors involved and their interactions play an important part in the functioning and well-functioning of the process.

As mentioned in the previous paragraph, the exclusion power of traces also needs to be counted among the utility dimensions of forensic science. Cases re-examined in the Innocence Project constitute excellent examples of this utility dimension: DNA matches with the profile of a person different to that of the convicted lead to the exoneration of the wrongfully convicted (Innocence Project, 2016).

The reason for use of a trace refers to the question of what information is expected from the use of the trace. One needs to consider the expected utility of the clue in order to understand why some traces are analysed, whereas others remain unanalysed.

By extrapolating, the decision not to use a trace is also of importance as the reasons for not analysing a trace are not known. It remains unclear if the non analysis of some traces is the mere consequence of the analysis of other traces that were chosen for analysis or if the decision not to analyse some traces was a conscious, deliberate choice against the analysis of these traces. In some cases, the first hypothesis may be applicable, with some traces remaining because others were analysed. Whereas, in other cases, some traces are deliberately not analysed, due to the reconsideration, at hindsight, of the quality or the pertinence of the trace as being low. In addition, external factors such as backlogs can contribute to the non-analysis of traces. When one knows that it is going to take a long time until a result from the analysis of a trace is obtained, efforts are going to put elsewhere in order to progress in the case, and collected traces will thus remain unanalysed.

According to its definition, utility of the clue depends on the information already available in the case. Thus, in the scope of this study, the utility dimension is translated to the following variables, encompassing information regarding the suspect, previously performed analyses and their outcome (see Table 6.4 for detailed explanations):

- suspect identification through police enquiry;
- number of biological traces analysed previously in the case;
- positive result available;
- identification (not necessarily the suspect) available through biological trace analysis;
- identification (not necessarily the suspect) available through other traces;
- identification (not necessarily the suspect) available total;
- suspect identification available before analysis through trace analysis.

Information potential

Traces have different information potential, given the actual situation and means. For instance, for fibres no database exists which records traces and/or reference material linked to people, hence, the possibility of linking cases on this basis is very limited (only in very specific, case-by-case basis and merely dependent on the memory of the crime scene investigator). In the past, biological traces were used to determine the blood group, and this information was used to discriminate between people. The information potential was limited by the technological advancements. The latter having developed rapidly, a DNA profile can now be extracted from the same biological trace, being much more discriminant, and potentially leading to the identification of a person through the introduction into a database. However, as mentioned in the section describing the decision to collate information in a structured database, some information is more prone to yield links than others, based on the type of crime and their seriality characteristics.

An example of this strategy was observed during the study phase at the forensic unit of the cantonal police Vaud, Switzerland. Three masked men, one with a red cap, robbed a kiosk. According to his testimony, the kiosk owner was violently attacked with a knife by the man with the red cap, while the others were either watching the door, or taking the money from behind the counter. The three men could flee before the police arrived, but were arrested soon after the events. Objects, linked to the events (knives, masks, caps) were confiscated from the suspects' car. None of the men admitted to having worn the red cap. In order to determine the degree of implication of the three men, biological traces from the knife and the red cap were sent to the laboratory for analysis.

6 Utility and the decision to analyse a trace

The presented concept of the utility of the clue is hypothesised to be used in the decision to analyse a trace as decisive factor. As utility of the clue depends on the information available previous to the analysis of the trace, investigators or prosecutors in charge of the case would need to take into account that information available in the case in order to decide on their subsequent steps and strategy for this factor to be considered important in the decision to analyse a trace. This hypothesis is tested through an empirical study, involving both quantitative and qualitative aspects. The decision to analyse a trace is formalised and the factors influencing this decision-making step, as suggested in the previously described knowledge dimensions, are determined through decision tree modelling.

The methodology employed throughout the studies is presented first.

A comparison of the crime scene attendance, trace collection and analysis strategies of three Swiss cantons is performed and the differences are discussed. Moreover, an in-depth study of the analysis strategy of the investigators of the forensic unit of the police of the canton Vaud is carried out and the independent factors influencing this triaging step are determined. Two dependent variables are modelled; the decision to analyse a trace in general – a looking-back scenario once all analyses have been completed –, and the decision to analyse a trace first – including the sequence of analyses. The section will start with a descriptive statistical analysis of the variables, both dependent and independent.

In complementary analyses, the influence of different independent variables particularly on the analysis, but also on the success, hit and pertinent hit rates is highlighted. Especially the variables involving previous knowledge of the case progression or trace processing as well as the physical aspects of the trace are of interest. The analysis rate corresponds to the number of analysed traces compared to collected ones. The success rate is the ratio of the number of analysed traces whose analysis yielded a positive result (a comparable profile) over the number of analysed traces. The hit rate corresponds to the ratio of hits generated from these positive results. Regarding DNA, although also *trace-to-trace* hits could be generated from the national database, the hits from our data are matches between the profile retrieved from a trace with the profile of a person registered in a database. For fingermarks, the hits are *trace-to-person* matches between a fingermark recovered at the scene or an object and a fingerprint from a person registered in the national database. Finally, the pertinent hit rate is the ratio of hits (suspect or victim), which are potentially useful to the case, compared to the overall number of hits. These can be suspect hits, but also hits with the victim's profile when the traces were recovered on the suspect or his belongings, for instance.

6.1 Common methodology

In this study, three research methods have been employed, in order to get a broad and detailed view of the subject under scrutiny. The first consists in the data analysis of past cases, which is quantitative in nature. This allows us to determine the frequencies of certain events or actions, in the light of other variables. Descriptive statistical analysis as well as decision tree modelling were performed to carve out the important variables influencing the decision to analyse a trace and to highlight the way in which they influence this decision.

The other two methods, namely interviews and participant observation, are qualitative methods. The ambitions of qualitative research methods are to grasp and to portray the behaviour, practices and daily routines of social actors under scrutiny. It aims at improving the understanding of the meaning and sense of their actions.

This mixed methodology was applied in order to complement the different results. At first, interviews were carried out with the head of the unit and one or two crime scene investigators (depending on the canton), in order to determine the work flow and decision chain for trace processing within their unit. These allowed us to determine for instance if guidelines for processing different types of traces exist and to identify the person in charge of deciding which traces to submit for analysis. Secondly, an extraction of their case file databases was provided for the quantitative analyses in order to confront with the previously obtained information. At last, a phase of participant observation was carried out, in order to qualitatively determine the reasons for analysis or non-analysis of different traces. The participant observation allowed us to gain inside knowledge of the practices and the interactions, within the unit but also with other brigades (such as the crime intelligence brigade).

As a general comment, we have to emphasise that the notion of 'analysis' needs to be understood in a broader sense, than the pure application of techniques to reveal the information from a trace. The 'simple' visual examination and interpretation of what is observed are considered here as an analysis. An example would be the analysis of a shoe mark in order to extract the shoe brand information or the pattern from it. This trace does not necessarily need the application of additional revelation techniques in order to be ready for analysis, nor being submitted to further comparison procedure.

6.2 Preliminary studies

These studies served as basis to elaborate the framework for the subsequent detailed study of the decision to analyse a trace, particularly in terms of type of trace to examine and the type of offence to concentrate on.

6.2.1 Comparison of the cantons

Studies were performed scrutinising commercial burglary cases in 2012 and 2013 in forensic units of three cantons in the Western part of Switzerland (Mobilia, 2014; Ermel, 2015). The aims were twofold. A quantitative study was carried out to depict the actual situation through descriptive statistics of the types of traces that are collected and analysed and their analysis rates. Through a qualitative approach, the reasons for the analysis and non-analysis of traces were determined, the actors involved in the decision-making process identified and existing guidelines and their application examined.

The quantitative data was extracted from the respective operational databases of the forensic units. Microsoft® Excel was used to collect and codify the data, Tableau® Desktop Software and R® Software were used to visualise the data.

For these studies, as described in the methodology, the qualitative collection procedure was performed through an interview with the head of the forensic unit and one or two crime scene investigators, depending on the canton, before beginning the participant observation within each of the forensic units of the three cantons during 6 weeks.

Cantons

Three cantons – Geneva (GE), Neuchâtel (NE) and Vaud (VD) – were studied. Their population data (Office fédéral de la statistique, 2014a), number of crime scene investigators working at the forensic unit and their budget for DNA analysis in 2013 (see Pitteloud, 2014) are represented in Table 6.1. The cantons were chosen based on their difference in size (Figure 6.1), hierarchical structure and organisation, as will be explained below.

The situations depicted regarding the organisation and strategies in place in the different cantons were prevailing at the moment of the study, beginning of 2014 for Vaud and Geneva and beginning of 2015 for Neuchâtel (time period of the participant observation). Between 2014 and beginning of 2015, no changes were applied to the organisational structure of the cantons Vaud and Geneva, all three cantons can thus be compared. In addition, the structures did not change compared to 2012 and 2013, time range of the studied past cases. Yet, the organisation has changed in some regards for the canton Geneva since the end of 2015, but these changes will not be discussed here.

In the canton Geneva, the *Brigade des cambriolages* (BCAM, burglary brigade) is requested to every reported burglary case, except for attempted burglaries. The burglary brigade is constituted of about 30 crime scene investigators, which are mainly police officers having had a quick introduction to forensic science and their collection procedures. It has to be noted that the training of forensic science received by the crime scene investigators of the burglary brigade in Geneva focusses mainly on biological traces. Twenty additional crime scene investigators, generalists of forensic science, belonging to the *Brigade de Police Technique et Scientifique* (BPTS, Forensic scientists) handle all other types of crimes. When the crime scene investigators from the burglary brigade decide to analyse a biological trace, they have to submit it to the forensic scientists, who are going to make the final decision whether the trace will be analysed or not. Guidelines exist regarding the number of biological traces to be submitted for analysis (1) for high-volume crimes, such as burglary. Additional

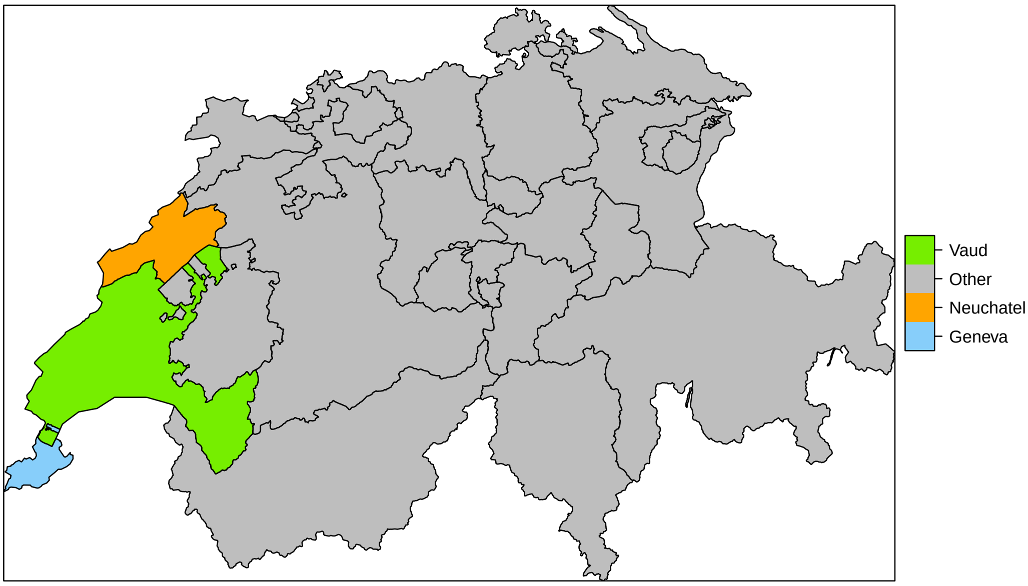

Fig. 6.1.: Maps of the three Swiss cantons under scrutiny in this study.

criteria for choosing the biological trace for analysis relate to the physical aspects of the trace, the matrix and the type of traces. The matrix preferences are based on the statistics of the hit rates obtained for previously analysed traces on different matrices.

In the canton of Neuchâtel, the hierarchy is very flat and every crime scene investigator investigates all types of offences. They decide on their own and without strict guidelines, which and how many traces are analysed in the case. In principle, no more than two biological traces should be analysed for a burglary case, however this number is said to be flexible if justifications are given. Exceptions occur when the case is linked to other cases. Then, the decisions are made in common with the investigator in charge of the other case(s). Generally, a maximum of two biological traces are submitted for analysis per case, however, when considered necessary, additional traces can be submitted (Ermel, 2015). This flexible system is also facilitated by their higher-than-average budget for biological trace analysis compared to all other Swiss cantons (Pitteloud, 2014) (see Table 6.1).

In the forensic unit of the canton Vaud, the crime scene investigators handle all types of cases and are also responsible for their cases. They decide, thus, which traces to analyse themselves or to submit for analysis. However, a biologist working with the investigators assists their choice regarding the decision to analyse a biological trace

Tab. 6.1.: Population data, number of crime scene investigators and DNA analysis budget in 2013 for the three cantons under scrutiny. Values for DNA analysis budget taken from Pitteloud (2014).

Canton	Population 2013	Number of crime scene investigators	Budget for DNA analysis in 2013 (CHF)
GE	472336	about 30 BCAM + 20 BPTS	1,940,000
NE	177833	about 20	1,090,000
VD	758614	about 20	900,000

depending on the matrix and type of biological trace. Similarly to the canton Geneva, in principle only one biological trace can be analysed per case in high-volume crimes (Identité judiciaire du canton de Vaud, 2013). However, in this canton, the matrix preferences are based on the statistics regarding the success rates of previously analysed traces on different matrices, instead of the hit rates as in canton Geneva.

The previously mentioned guidelines are valid for biological trace analysis, as this type of trace is submitted to an external laboratory, which results in additional costs for the forensic unit or the prosecutor's office (depending on who is in charge of the case). No guidelines exist regarding the collection and analysis of all the other types of traces. In all cantons, the head of the forensic unit as well as the crime scene investigators asserted that all collected fingermarks and shoe marks were analysed.

Neuchâtel and Vaud put in place a case selection procedure. Depending on the seriousness of the offence, the presence of visible traces, the transportability of objects, the time of events, etc., police officers already present at the scene can collect items and deliver them to the laboratory of the forensic unit instead of requesting the intervention of the crime scene investigators of the forensic unit. Depending on these factors, the crime scene investigators do not perform an investigation themselves on the crime scene, but search for traces on the collected items brought to laboratory by police officers. Geneva, on the contrary, has implemented a different strategy for burglary cases: all reported cases are investigated by the burglary brigade.

Case attrition prior to analysis

In the canton Vaud, every event reported to the police is initially registered in the *Journal d'Evenement Police* (JEP, Police Event Journal). Similar databases exist in the other cantons. This database does, however, not reliably reflect the number

Tab. 6.2.: Number of reported completed burglary cases (N) per canton for 2012-2013 according the OFS and PICAR and relative rates (N/sum(N)) to illustrate the cantonal distribution. Rate of commercial burglary cases registered in PICAR to the total number of burglary cases reported by the OFS. All rates are in %.

Canton	According to OFS		According to PICAR		PICAR / OFS
	N completed burglary cases	Rel. rates	N commercial burglary cases	Rel. rates	Rate of comm. burglaries to burglaries
GE	12031	35.6	3451	33.9	29
NE	3262	9.6	1309	12.9	40
VD	18518	54.8	5410	53.2	30

of committed commercial burglary cases, as multiple entries in the database can refer to the same case, biasing thus the number of offences. Furthermore, details about the cases are not codified in a standardised way. These inconveniences have been identified and remediated in the crime intelligence database, PICAR (see Birrer (2010)), and thus the number of missed or wrongly codified offences can be assumed to be relatively low. Instead of using JEP, PICAR was used to retrieve the number of reported offences of commercial burglaries and compared to the number of commercial burglary cases registered in the database of the forensic unit. Once their service requested, crime scene investigators at the forensic unit import the event from JEP into their case file database. They then decide whether they go to the location of the event and conduct a crime scene investigation or if objects can be collected by police officers already at the scene and delivered to the laboratory. The results of the crime scene attendance strategies for the three cantons are shown in Figure 6.2.

The number of reported offences, and thus registered in the crime intelligence database, is very variable from one canton to another, with Vaud being on top of the ranking and Neuchâtel at the bottom. This difference in values follows the difference in population size of the different cantons (see Table 6.1). For comparison, the number of completed burglary cases as reported by the Federal Statistical Office for the three cantons indicate similar relative ratios of completed burglary cases (Office fédéral de la statistique, 2014b) (see Table 6.2). In these official statistics, it is not possible to extract the values for commercial burglaries. Neuchâtel has a slightly higher rate of commercial burglary cases compared to the total number of burglary cases (40% for NE compared to 29% for GE, respectively 30% for VD). This might be explained by the proximity of the watch industry in the canton Neuchâtel or due to a difference in data collection within the three cantons. None of these hypotheses can be confirmed at this stage. Regarding the number of cases handled by the forensic unit, the order is changed, with Geneva on top.

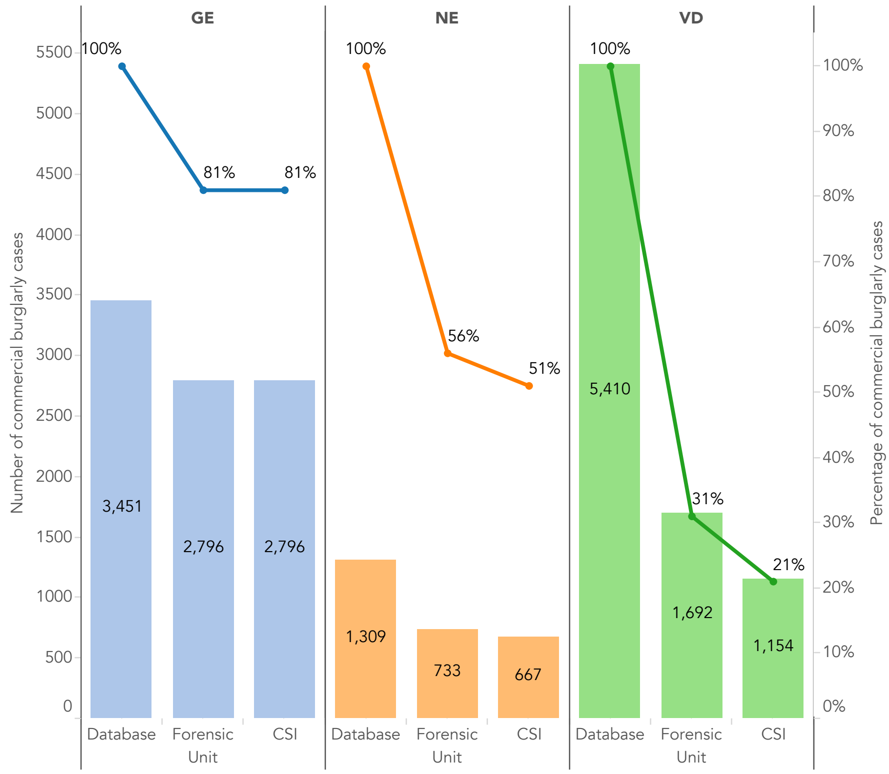

Fig. 6.2.: Number of commercial burglaries registered in crime intelligence database, reported to the forensic unit, and number of crime scene investigations (CSI) of these cases per canton in 2012-2013. The lines show the percentage of cases registered in the crime intelligence database, in the database of the forensic unit, and the cases where a crime scene investigation was performed.

The lines in Figure 6.2 for each canton give an idea about the strategy in place regarding crime scene intervention (see decision steps 1 and 2 in section 3.2). The general tendencies of the lines are very different depending on the canton and showcase thus the difference in crime scene attendance strategies.

In Geneva, 81% of cases that are reported to the police are also added to the database of the forensic unit and are thus the object of a forensic operation. As previously stated, the burglary brigade is requested in every case, except for the attempted burglaries (which are thus not registered in the database of the forensic unit). The remaining 19% of reported cases are possibly equivalent to the percentage of attempted burglaries. According to the statistics of the Federal Statistical Office (Office fédéral de la statistique, 2014b), 24% of the total number of reported burglaries in Geneva in 2012-2013 (15770) were registered as attempted burglaries (3739). A crime scene investigation takes place in 100% of the cases registered in the forensic unit database. Indeed, the objective of the implementation of the burglary brigade was to be able to investigate all reported burglary cases without a previous case attrition step.

The police of Neuchâtel follows a different strategy: in 56% of reported cases, the forensic unit is informed and involved, whereas in only 9% of the 733 cases reported to the forensic unit, no crime scene investigation took place, but objects were collected at the crime scene by police investigators and delivered to the forensic unit for analysis. With these case attrition values and their case triaging strategy, they lie in the middle of the three cantons.

In Vaud, however, a huge attrition of cases occurs already at the first step: in only 31% of cases reported to the police, the forensic unit is informed and a forensic operation takes place. Thus, first responders must infer that only very few cases have useable traces, which would need an implication of the crime scene investigators of the forensic unit. Subsequently, another 30% of cases are filtered out: in roughly 70% of the 1692 cases reported to the forensic unit, the crime scene investigators go to the location of the offence and perform a crime scene investigation. In the remaining 30% of cases, objects were recovered by police first responders and delivered to the forensic unit for analysis.

Trace attrition

The trace attrition values for different types of traces, per canton, are compared and the results are shown in Figure 6.3. For biological traces, the absolute number of collected and analysed traces is substantially higher for Geneva than for the other two cantons. However, when normalising by the number of cases handled by the forensic unit of the respective cantons, Neuchâtel collects and analyses the highest number of biological traces per case. Considering their higher-than-average budget compared to other cantons (when normalised by the number of inhabitants or the number of offences (Pitteloud, 2014)), this result mirrors their strategy of opting for the analysis of a high number of biological traces. For this type of offence, biological traces undergo a very selective triaging procedure (see Figure 6.3). Due to the high number of collected biological traces and the analysis of this type of trace being

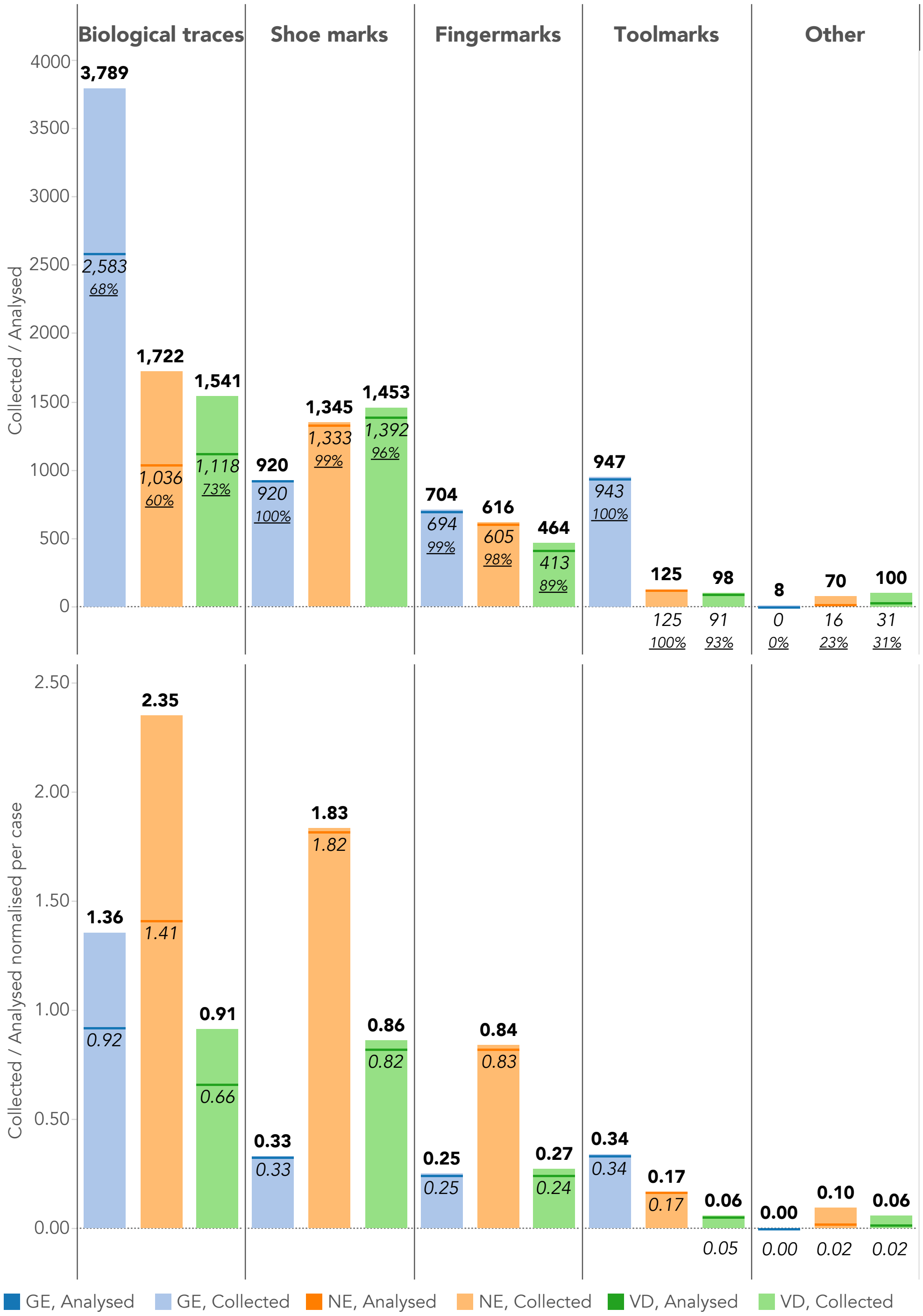

Fig. 6.3.: *Top:* Comparison of the number of **collected** and *analysed* traces, and <u>ratios</u> of analysed traces, per type of trace and canton. *Bottom:* Comparison of the number of **collected** and *analysed* traces per type of trace and canton normalised by the number of cases handled by the forenisc unit.

externalised, thus submitted to an external laboratory which incurs additional costs, by far not all collected traces can be analysed. During the interviews, guidelines regarding the triaging strategy of biological traces were presented in Geneva and Vaud. In these cantons, in principle only one collected biological traces should be analysed per case in burglary cases. In Neuchâtel, the crime scene investigators should restrict the number to 2. This factor is however frequently ignored, and more than one respectively two traces are analysed per case. In Figure 6.3, it can be seen that for Neuchâtel, the average number of analysed biological traces per case lies above 2. For the canton Vaud, in 135 cases, more than 1 biological trace is analysed (see Figure 6.4).

In addition, triaging criteria, based on the type of biological trace and the matrix it was collected from, were set up. The type of biological trace to be preferred are 'rich' biological traces, i.e. blood, saliva, etc., which are more prone to yield a positive result (i.e. a profile which can be compared) over contact traces. Regarding the matrix of the trace, the reasoning processes to decide on the best matrices are differing among cantons. In Vaud, the frequency of obtaining a positive result from the biological trace per matrix is the factor for deciding which traces are to be preferred for analysis. In Geneva, the frequency of obtaining a hit in the DNA database or with a known suspect is considered to be decisive for the triaging strategy. These criteria are determined based on statistical analysis of the number of positive results compared to the number of analysed traces per matrix (Milon, 2013; Milon and Albertini, 2013), respectively the hits obtained from these profiles from the different traces (see Baechler, 2016).

Similarly to the numerical factor, the guideline, regarding the type of biological trace, is not always followed either when choosing the biological traces for analysis (see Figure 6.4). In canton Vaud, when considering only the type of biological trace, in 624 of the 789 cases where one trace was analysed per case, the type of biological trace was not corresponding to the guidelines. Similar figures were found for Geneva. During the participant observation phase, it was determined that, indeed, crime scene investigators follow a much more flexible triaging strategy when choosing biological traces for analysis, than the one formulated in the guidelines, depending on the case and its circumstances. It must be noted that often only one, not necessarily 'rich' biological trace is collected, and thus this type of biological trace is analysed, whether or not it corresponds to the guidelines.

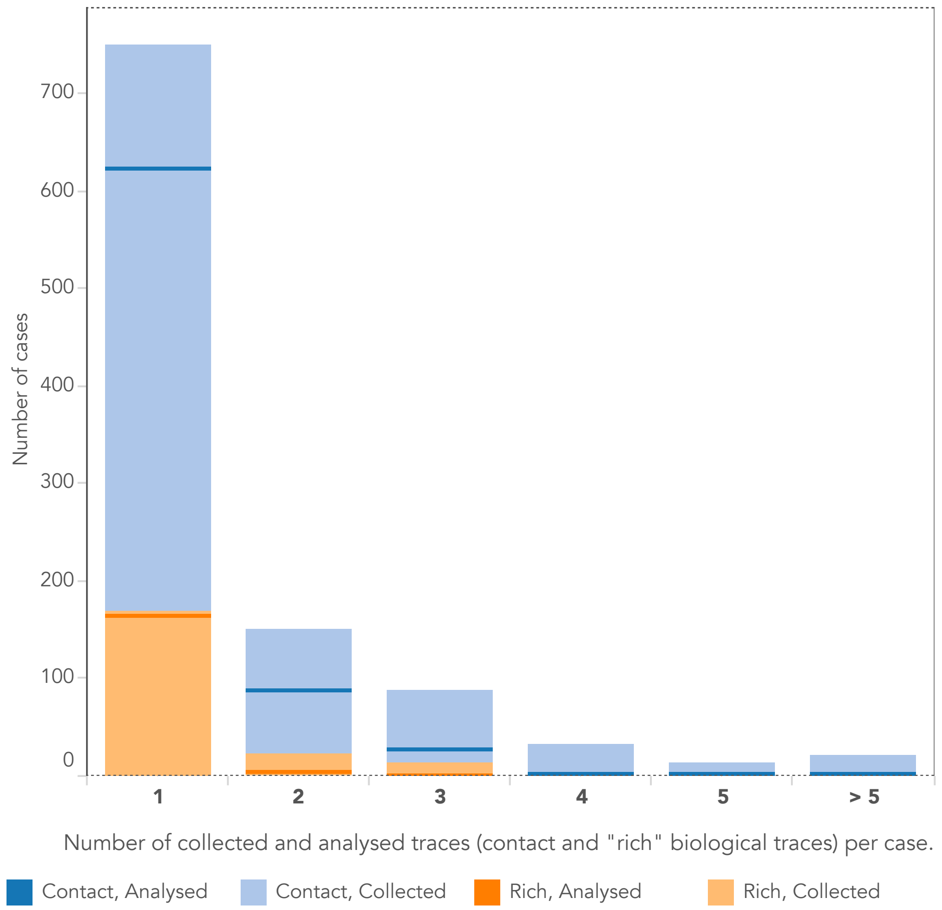

Fig. 6.4.: Number of collected and analysed biological traces per case and per type of biological trace for commercial burglary cases in the canton Vaud in 2012-2013.

Neuchâtel comes out at the top again for the number of collected and analysed shoe marks normalised by number of cases. This result however needs to be considered with care, because, it has come to light that the forensic unit registers two traces for the same pattern (left and right), whereas the investigators of the other cantons grouped these traces to one single trace in the database, with two pictures. Hence, the number of shoe marks is doubled (or at least increased) by the investigators of Neuchâtel.[1] For Geneva, the number of collected and analysed shoe marks is particularly low. This might be explained by the education and training, or lack of it, of the investigators of the burglary brigade. The main focus of their short training lies on biological traces, which is reflected in the data. In addition, due to their crime scene attendance strategy and thus high case load (they are requested for every reported burglary case), they are under time pressure and might not have enough

[1] No judgement whether their practices or that of the other cantons are right is intended. For comparison purposes, care must however be taken.

time to concentrate on shoe mark collection, for which the procedure of detection and collection is more time-consuming, compared to swabbing for biological traces. In the canton Vaud, there is a 'culture of shoe marks' (Girod et al., 2008): the crime scene investigators are used to collect and analyse this type of traces, and, regularly links between cases are found through shoe mark comparison. In addition, their crime scene attendance guidelines state that traces must be visible for them to be requested to conduct a crime scene investigation. Shoe marks are particularly prone to fall into the category of visible traces, and as crime scene investigators are requested to the crime scene due to this type of trace, it is often collected.

The absolute number of collected and analysed fingermarks are similar across the three cantons. However, normalised by the number of cases, Neuchâtel is again on top of the list.

A similar triaging strategy is applied for shoe marks and with a little more appreciation margin for fingermarks. Interestingly, when asked during the interviews about the analysis strategy for shoe marks and equally for fingermarks, the head of the crime scene investigators as well as the crime scene investigators themselves claim that all collected traces are analysed. However, when looking at the data, the analysis ratios are close to but not exactly 100% (see Figure 6.3, minimum for shoe marks is 89% and for fingermarks 96%). This discrepancy between the information given in the interviews and the actual data could be understood in the participant observation phase. Indeed, fingermarks and also shoe marks, can be selected and assessed upon their quality and redundancy at the moment of collection, but also right before analysis. Thus, an additional triaging criteria is applied when it comes to these types of traces. In this case, this qualitative triaging step takes place after the collection, and thus, before the analysis of the trace. However, some crime scene investigators prefer to triage already before the collection (or registration of the trace in the database).

Regarding tool marks, the crime scene investigators in Geneva know that one of their colleagues has a particular interest in this kind of traces, organises the collected traces and registers the related information in a database. Thus, they tend to collect these types of traces more often than their colleagues from the other cantons. It can be noticed that, for all cantons, when they are collected, they are also analysed. The analysis of tool marks encompasses their brief description, including the type of

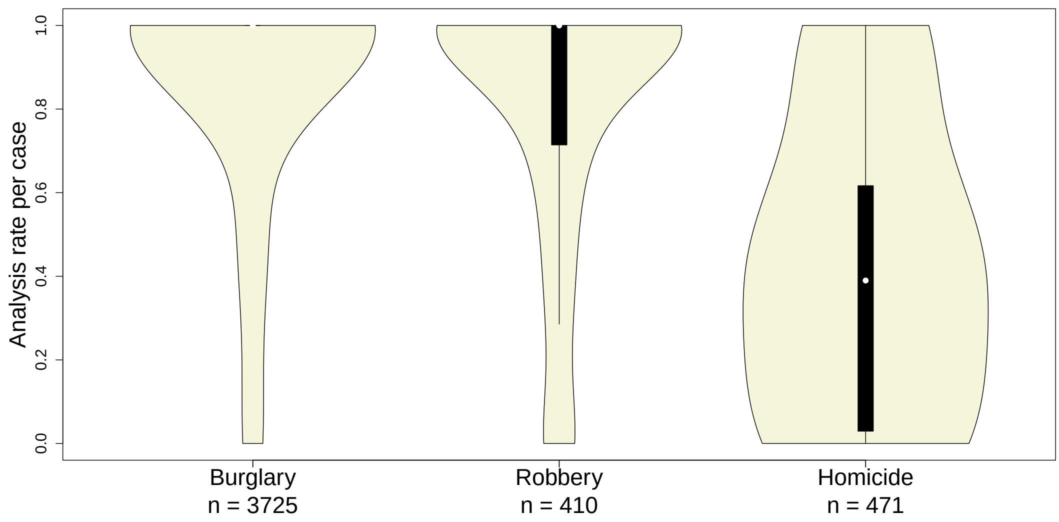

Fig. 6.5.: Distribution of analysis rates for biological traces per case per type of offence. Data from canton Vaud, 2012–2013. n = number of collected traces.

tool allegedly used, colour and dimension of the mark, as well as the comparison of striation to link cases.

The number and proportion of other traces (ear marks, micro traces, etc.) are negligible for all three cantons.

6.2.2 Comparison of robbery, homicide and burglary cases

The data used in this study originate from the case file database of the forensic unit of the canton Vaud, from 2012 and 2013. The cases with at least one collected biological trace are considered. Violin plots are used to represent the distribution of the data; they are box plots with density trace plots (smoothed histogram) on each side (Hintze and Nelson, 1998). Violin plots include a point for the median of the data (instead of a line as in a box plot) and a box indicating the interquartile range, as in standard box plots. The box plot shows the separation of the data into the percentiles of 25%, 50% and 75%, also called the first (*Q1*), second (*Q2*) and third (*Q3*) quartile, respectively. The 25% percentile (*Q1*) corresponds to the value to which 25% of the data are inferior and 75% superior. The second quartile (*Q2*) corresponds to the median. The interquartile range corresponds to the difference between the first and the third quartile. The overlaying density trace plot provides a better indication of the shape of the distribution. This representation is particularly useful to compare the characteristics of the different distributions.

Tab. 6.3.: Descriptive statistics of the number of collected and analysed biological traces per case per offence type.

		Collected traces				Analysed traces			
	N cases	**n**	**mean**	**median**	**Std dev**	**n**	**mean**	**median**	**Std dev**
Burglary	2720	3725	1.4	1.0	1.0	2842	1.1	1.0	0.6
Robbery	101	410	4.1	2.0	5.1	302	3.0	2.0	3.7
Homicide	19	471	24.8	20.0	23.5	237	12.5	10.0	16.3

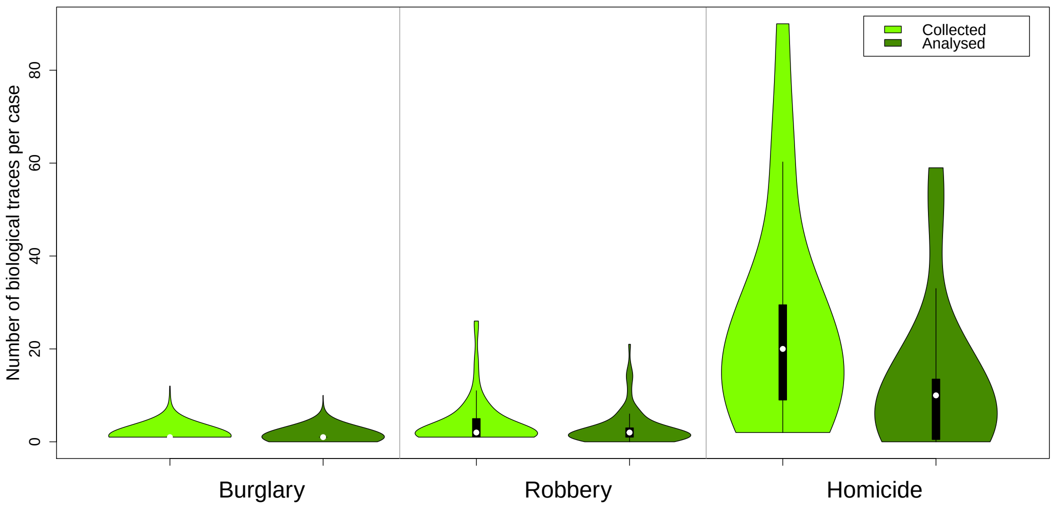

Fig. 6.6.: Violin plots of the number of collected (light green) and analysed (darkgreen) biological traces per case per type of offence. Data from canton Vaud, 2012-2013.

When comparing solely the analysis rates for biological traces of burglary, robbery and homicide cases, a seemingly surprising result is found (see Figure 6.5). In burglary cases, the analysis rate is close to 1 (nearly 100% of collected traces are analysed), with a pronounced trend towards 1 in the distribution (median = 1, average analysis rate 0.78), with only a small number of cases having analysis rates smaller than 1. Robbery cases have an increasing number of cases that is affected by more triaging, thus more selection is done and the final analysis rate is lower (median = 1, average analysis rate 0.74, see particularly in the box plot). In homicide cases, the analysis ratio is more dispersed (median = 0.39). The average analysis rate lies at 50%. The data distribution mainly ranges between 0.03 and 0.62 of analysis rate for their first (*Q1*) and third (*Q3*) quartiles.

As highlighted by other researchers, in high volume crimes, cost-effectiveness appears to play a role when choosing traces for analysis and the triaging is anticipated to the previous decision step, the collection of traces (Wilson-Kovacs, 2014). The guideline for burglary cases, allowing the crime scene investigators to analyse one trace per case probably influences already the collection step. Whereas in homicide cases, crime scene investigators tend to collect more widely, without much triaging taking place during the collection phase. Indeed, the results presented in Table 6.3 and Figure 6.6 show the collection and analysis values and highlight the shift in the decision-making process in burglary cases, i.e. the anticipation of the triaging strategy to the earlier decision step.

In burglary cases, on average 1.4 biological traces are collected per case and 1.2 traces are analysed per case. In robbery cases, an average of 4.1 biological traces are collected per case, and 3.0 are submitted for analysis. Finally, for homicide cases, 24.8 traces are collected per case on average and 12.5 are analysed. As the absolute number of collected traces is very high for homicide cases, it is comprehensible that a more severe triaging step is undertaken. In the 19 cases of homicide in 2012–2013, more biological traces were collected in total compared to the 101 robbery cases in the same time period.[2]

6.2.3 Discussion

Burglary cases are part of the routine case load of the crime scene investigators. However, the different cantons are confronted with different numbers of cases, different resources and constraints, which influence the number of crime scene investigations. Neuchâtel intervenes on double the number of reported cases compared to Vaud, which, in turn, handles 5 times the number of cases. Intervention strategies need to be put in place corresponding to the available resources. In Geneva, due to their organisation of one brigade specialised in burglary cases, crime scene investigators are able to intervene on all reported cases.

Not all collected traces from commercial burglary cases are analysed, a triaging procedure is thus applied. The analysis of fingermarks and shoe marks is financially justifiable, as they are performed in-house by the crime scene investigators themselves. Thus, (nearly) all collected traces are analysed, except for those considered as non-relevant, of insufficient quality or redundant. When it comes to the other types of traces (tool marks, micro traces, glove marks), it is difficult to determine their actual use in the investigation, as the number of cases with these types of traces is extremely low. Biological traces are the prevailing type of trace according to

[2] While checking the data for the supplementary analyses, it was noted that there were 101 cases included in the study, instead of 102 as stated in the article (see Bitzer et al. (2016)).

the number of collected and analysed traces. However, due to their high collection numbers, a selective triaging procedure is applied to biological traces, which are submitted to an external laboratory for analysis. In summary, it is noticed that the established guidelines, based on strategic and physical aspects of the trace, are loosely followed by the crime scene investigators when choosing the traces for analysis. In summary, for the subsequent study, the focus is set on biological traces as most of the triaging occurs for this type of trace. For the other types of traces, analysis rates close to 100% were determined, which leads to the hypothesis that the triaging of these traces occurs already at an earlier stage, during the collection of the traces at the crime scene.

The preliminary studies focussed on commercial burglary cases as it was necessary to reach a substantial number of observations during a limited period of time, particularly important for the participant observation phase. The existing guidelines were applicable mostly for burglary cases and thus the influence of this dimension could be examined through this study. Homicide cases often involve a high number of collected traces, whereas the analysis rate can range from 0 to 100%. Hence, it would be interesting to examine the influencing factors for this type of offence. However, (luckily) only a relatively small number of cases occur annually, resulting in only a small dataset and leading to a prolonged observation phase. Robbery cases can be considered to be a hybrid form between burglary and homicide cases regarding the analysis rate of biological traces per case. Indeed, when performing a case study of robbery cases, it could be noticed that some cases are considered of minor importance, and are handled in a similar way to burglary cases (some even without crime scene investigation), whereas other cases, where the victim was fiercely attacked, were considered very serious and handled like major crimes (more traces were collected and analysed). The focus is thus set on robbery cases as they are considered to be a good compromise between these two types of cases, as triaging occurs and an actual decision step is undertaken.

6.3 In-depth study

Except otherwise stated, the data – both quantitative and qualitative – used for these analyses encompass 101 robbery cases, with (at least) one collected biological trace, registered in the database of the forensic unit of the canton Vaud between 2012 and 2013.

Both, the *a priori* and *a posteriori* results will be presented here. The *a priori* results correspond to the state of the case prior to trace analysis. Traces have been collected but not yet analysed. For example, if a suspect has been identified at this moment, forensic science can not have contributed to this identification. In this situation, the utility of the clue can however be for confirmation, reconstruction, implication, etc. Whereas, the *a posteriori* results are compiled once all analyses have been performed and the results obtained. The enquiry can be closed but it is not necessarily the case. These results will be discussed in Chapter 7.

This distinction is important as the consideration of previously available information constitutes one building block of the concept of utility (see Chapter 5). A difference exists in assessing the utility *a priori*, and thus also the expected utility at the moment of the analysis, versus the utility *a posteriori*, the actual utility after the analysis, taking into account the result of the analysis. For instance, the knowledge of a crime link of the case in question with another case through police enquiry before the analysis of the trace, will eliminate the utility of crime linking as utility *a priori* of the clue or the expected utility. Whereas, if this information is gained after the analysis, the initial utility *a priori* of the clue, expected utility, can include crime linking, but the utility *a posteriori* of that same clue will not include crime linking. This applies in analogous manner to all other potential utility dimensions. Hence, the information available at that moment through other sources (mostly police enquiry or previous trace analysis), is important when assessing the utility of the clues.

6.3.1 Case resolution: *a priori*

According to the Swiss police statistics (Statistique policière de la criminalité, SPC) (Bundesamt für Statistik, 2015), a case is considered solved, when one offender of the case could be identified, even if the case was committed in a collective manner. Despite its use in the SPC, in the scope of this study, this definition is not retained. In cases considered solved according to the SPC definition, additional suspect(s) might remain unidentified. Thus, in these cases, when considering the identification utility perspective, it still makes sense to analyse traces, in an attempt to reveal the identity of the offender(s). Whereas, in actually solved cases (all suspects have

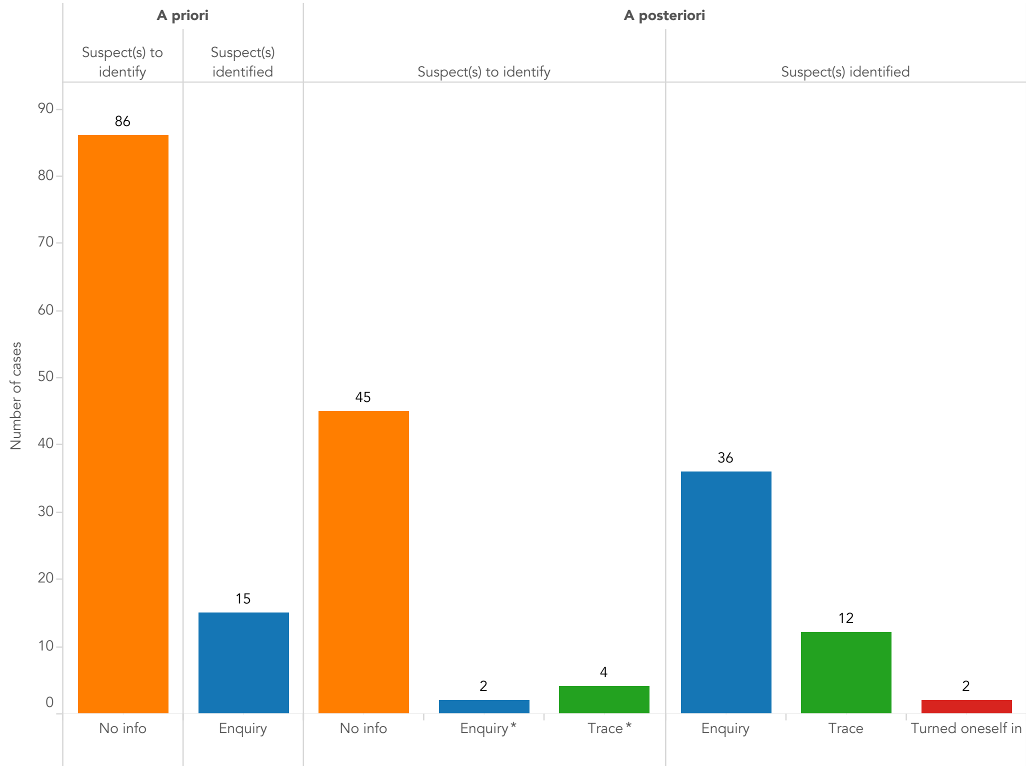

Fig. 6.7.: Case resolution *a priori* and *a posteriori*. Separation done on the basis of the potential utility of identification. Either no identification information has been yielded, or it has been yielded through police inquiry, trace analysis or the offender turned himself in. The fields marked with (*) refer to cases where a suspect has been identified either through police enquiry or trace analysis, however, (at least) one offender still needs to be identified.

been identified), analysing traces for their identification potential is not considered useful.

The case resolution values are shown in Figure 6.7. *A priori*, previous to the analysis of traces, in 15 of the 101 cases, the suspect(s) had already been identified (Suspect(s) identified, hereafter SI) through police inquiry. In these cases, as stated above and given that the decision-maker is aware of this information, the identification utility of forensic science is null. If forensic science is used, the purpose must be different to identification (confirmation, reconstruction, legal qualification, etc.). In the remaining 86 cases, no information regarding the identity of the offender(s) was available (Suspect(s) to identify, hereafter STI) prior to the analysis of biological traces.

As previously mentioned, the results *a posteriori* will be discussed in Chapter 7.

6.3.2 Decision to analyse a trace

The aim of this study is to broaden the knowledge and understanding of the decision-making steps in the criminal investigation, especially the decision to analyse a trace. As previously mentioned, the focus is set on triaging of biological traces in robbery cases. At first, the data and methodology are presented, followed by the results and concluding with a discussion of the obtained results.

Data and method

The paragraphs with the following style are reproduced verbatim from Bitzer, S., Ribaux, O., Albertini, N., and Delémont, O. (2016). To analyse a trace or not? Evaluating the decision-making process in the criminal investigation. Forensic Science International, 262:1-10. Explanatory details are added in normal style.

Study data and methodology We studied robbery cases[3] occurring in the canton Vaud (a region of Switzerland of 3212 km^2 and 760 861 inhabitants) between January 2012 and December 2013. More precisely, we examined the data recorded by the forensic unit of the police (state police) and considered robbery cases where at least one biological trace was collected. These cases can be very diverse, from the street robbery of a handbag to the highly organised and planned robbery of a jewellery store or bank. Robbery cases were chosen as compromise between high volume crimes, where the decision to analyse a trace does not involve much of a triaging decision based on reasoning about the usefulness of the clue (criteria used are much more global, in accordance with financial limits), and homicide cases. The canton Vaud was chosen as study area for proximity reasons.

First, we performed an extraction of information from the police database: 102 cases were registered in the database of the forensic police unit for the type of

[3] Robbery is legally characterised by Art. 140 Swiss Criminal Code as follows: "Any person who commits theft by using force on another, threatening another with imminent danger to life or limb, or making another incapable of resistance" (Code pénal suisse, 2016). We use it as a definition for delineating the kind of events we aim at covering. More precisely, cases that were first reported as being robbery cases were studied. In fact, in 10% of these cases, the legal classification changed later in the course of the investigation and the suspect was finally charged for a different offence (e.g. burglary, aggression, misleading the judicial authorities).

event and the selected period. This corresponded to a total of 410 biological traces. In 12 and respectively 38 cases, fingermarks and shoe marks were also collected.

This dataset was completed with qualitative data through participant observation that was performed during 5 months at the forensic unit in the beginning of 2015. It was possible to follow two cases at the crime scene and another 20 were observed during the decision process at the laboratory. During this period, additional information about the cases was collected. This allowed integrating pieces of information that are typically not included in the structured scheme of the database, such as the case progress before submission for analysis (e.g. if a suspect was identified before the analysis of the trace) or the contamination of the crime scene by the victim after the events. This mixed methodology allowed for a more comprehensive account of the complete decision-making process, and particularly the decision to analyse a trace. The principal aim of the participant observation was to help further our understanding of why a trace was analysed (or not). Furthermore, the results could be more easily interpreted by having seen and followed cases from the start to the decision to submit traces for analysis.

During the participant observation phase, 22 cases could be followed while being at the forensic unit of the canton Vaud during 5 months. For two of these cases, the crime scene investigation could be accompanied. In these cases, a specific focus was set on the crime scene investigation (search and collection of traces), the people present at the scene, the information available at the moment of trace collection, the evaluation of the relevance and pertinence of the traces by the crime scene investigators, etc. For the remaining 20 cases, the cases were followed once the crime scene investigation had been performed. For these cases, a description of the case was retrieved from the database and completed with information provided by the crime scene investigator regarding the previously mentioned questions. In addition, the decision-making process regarding trace processing was discussed with the investigator with particular focus on the choice of traces to submit for analysis after the crime scene investigation. In the course of the investigation, their (updated) triaging strategy was discussed once results were obtained. By complementing the quantitative data and results with this qualitative collection technique, interpretative biases can be avoided.

Variables The dichotomous dependent variable considered is the *Analysis of a trace*: whether the biological trace was analysed or not (1 = trace was analysed, 0 = trace was not analysed). In this study, we considered that the analysis of a biological trace consisted in its DNA profiling performed by an external DNA laboratory; visual examination or presumptive testing to inform the collection or the type of biological trace were not considered an analysis.

More often that not, the different traces collected in a given case are processed in successive batches of analyses: they are not all submitted at once to the external laboratory for DNA profiling. Therefore, we decided to adopt a double perspective in our study: a first model was considered taking into account the dependent variable (analysed traces) at the end of the investigation, after all analyses were performed. A second model was considered using the first batch of analysed traces in the case as dependent variable (the traces that were analysed in the first batch were coded 1, all the others were coded 0, even if they were analysed in a second, third, . . . batch). This dual perspective was chosen in order to follow the sequence of the analyses and get an understanding of what factors were affecting the composition of the first batch of analyses.

The independent variables were separated into the four environments defined by Ribaux et al. (2010a) with the addition of a utility knowledge dimension, including previously available information (see Table 6.4). Some variables are case-specific, and thus the same for all the traces in the case, whereas others are trace-specific.[4]

The *strategic*, *immediate*, *criminal* and *physical* knowledge dimensions were first presented in section 3.2.1 and the *utility* knowledge dimension in Chapter 5. Additional detail is given here.

The *strategic* dimension includes the question of *Who*, whether the prosecutor or the investigator (police or crime scene) is in charge of the case. The fact that a prosecutor is in charge of the case does not necessarily involve that he made the decision regarding the trace processing. However, the financial aspect is (partly) reflected in this variable, as, when the prosecutor is in charge of the case, his budget will be used instead of the police's. One must keep in mind that in some situations, the trace analysis was requested by the crime scene investigator, and once a hit was obtained, the case file was transferred to the prosecutor, who became then in charge of the case. The final actor in charge of the case is registered in the database.

[4] An example of the data for one case is given in Appendix B.

Tab. 6.4.: Description of independent variables. Variables in italic are not available for the second model (first batch of analyses). For the sake of simplicity, the term “identification” of the suspect will be used here. However, this should not be understood in an evaluative/interpretative manner. For the nominal variables, dummy variables were created.

Variable	**Type**	**Case or trace-specific**	**Description**
Strategic			
Type of intervention	binary	case	Crime scene investigated by forensic unit (predictor) or objects brought to laboratory by police first responder
Prosecutor in charge of the case	binary	case	A prosecutor was in charge of the case, and thus in charge of DNA analyses. In the investigated area, the police start the inquiry. In some situations, a prosecutor is introduced in the procedure.
Team of inspector in charge	nominal	case	Crime scene investigators at this forensic unit are separated into 5 teams.
Number of collected biological traces	ordinal	case	Number of collected biological traces registered in the database for the case.

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Tab. 6.4 – *Continued from previous page*

Variable	**Type**	**Case or trace-specific**	**Description**
Immediate			
Type of target	nominal	case	Three categories: business (i.e. jewellery store, post office), service (i.e. café , bar, restaurant) and private, (i.e. apartment, street, parking lot)
Surveillance camera	binary	case	Predictor [5]: surveillance camera images available, no information about the quality of these images.
Witness report	binary	case	Predictor: witness report available, no information about the quality of this report.
Armed robbery	binary	case	Predictor: a weapon (gun, knife, ...) was used.
Violence against victim	binary	case	Predictor: the victim was hurt by the offender(s).
Number of offenders	ordinal	case	Number of offenders described in the summary of the case.
Number of collected shoe marks	ordinal	case	Number of collected shoe marks registered in the database for the case.
Number of collected fingermarks	ordinal	case	Number of collected fingermarks registered in the database for the case.

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[5] The predictor corresponds to the state of the binary variable that is coded 1. Here, the availability of the surveillance camera images is coded 1, and the non availability of these images is coded 0.

Tab. 6.4 – *Continued from previous page*

Variable	**Type**	**Case or trace-specific**	**Description**
Physical			
Type of biological trace	binary	trace	"Rich" biological trace (blood or saliva; predictor) or contact trace.
Presumptive testing	binary	trace	Predictor: presumptive testing was performed.
Matrix of the trace	continuous	trace	Probability of obtaining a positive result (which can be used for comparison) on a specific matrix in the year previous to the decision about analysis of this trace, compiled from all analyses of biological traces in the database (for all types of crimes).
Criminal			
Known crime link	binary	trace	Predictor: crime link is known, as registered in the database, the link is known before the analysis of the trace.
Utility			
Suspect identification through police inquiry	binary	case	Police inquiry led to the identification of a suspect before analysis of the trace.
Number of biological traces analysed previously in the case	*ordinal*	*trace*	*Number of biological traces analysed in the case previously to the trace in question.*
Positive result available	*binary*	*trace*	*Positive result (a profile suitable for comparison) available within the specific case before analysis of the trace.*

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Tab. 6.4 – *Continued from previous page*

Variable	**Type**	**Case or trace-specific**	**Description**
Identification available through biological trace analysis	*binary*	*trace*	*Suspect identification by DNA analysis before analysis of the trace.*[6]
Identification available through other traces	binary	trace	Suspect identification by other types of traces before analysis of the trace.[7]
Identification available total	*binary*	*trace*	*Identification by DNA or other types of traces before analysis of the trace.*
Suspect identification available before analysis	*binary*	*trace*	*Suspect identification through DNA analysis available before analysis of the trace.*[8]

[6] The identification does not necessarily yield the suspect. Corrigendum: Identification by by DNA analysis before analysis of the trace.
[7] *Idem.*
[8] The suspect identification is not necessarily yielded through biological trace analysis. Corrigendum: Suspect identification before analysis of the trace.

The *immediate* knowledge dimensions includes the number of offenders. This information was retrieved from the summary of the cases in the database and updated, when necessary, in solved cases with the information from the police enquiry.

The *utility* dimension encompasses the question of *When*, in regards to the other available information, which involves the identification of a suspect. As stated in the caption of Table 6.4, the term 'identification' should not be understood in an evaluative/interpretative manner. In this study, this term is used to indicate that an individual could be linked to the case in question, whether it be through police enquiry or trace analysis. No statistical evaluation of the force of this link was undertaken.

Analytical strategy Classification modelling was performed in order to create models that best explain our data. Recursive partitioning methods, including decision tree- and rule-based models, were used to follow the decision steps and highlight and select the important factors in our model. Details about the chosen statistical procedure can be found in Kuhn and Johnson (2013). These algorithms split the data in multiple steps in order to discriminate a maximum of the observations. Each dataset was split until the remaining subsamples consisted mainly of one group (i.e. classification). These classification modelling algorithms had several advantages, such as the possibility of integrating various types of variables (binary, ordinal, continuous) into the model and little influence by extreme values or by missing data. Simple decision tree modelling algorithms, like CART, j48, and single decision tree C5.0, were used and compared with performance results of more complex models, like boosted C5.0, rule-based PART, bagged trees (treebag) and boosted trees (gbm). The raw data were extracted from the operational database of the forensic police unit and were completed with information retrieved from audition reports. Microsoft® Excel was used to collect and codify the data and the open source software R® was used for further statistical modelling.

Classification trees and rule-based models consist of nested if-then conditions (Kuhn and Johnson, 2013). Decision trees are composed of nodes, which represent a 'test' on an attribute (i.e. the above-mentioned independent variables), branches, which represent the outcome of the test, and leaf nodes, which represent the decision taken after computing all attributes.[9] If-then statements generated by a tree define a unique route to one terminal node for any sample; this path from the root to the leaf represents a rule. A rule is a set of if-then statements that have been collapsed into independent conditions. The fully grown trees may be very large and are likely to overfit the training set. The tree is then pruned back to a potentially smaller depth, using the cost-complexity tuning parameter (Breiman et al., 1998). The aim is to find a 'right-sized tree' that has the smallest error rate. The categorical variables were transformed into dummy variables, i.e. binary variables for each one of the categories of a categorical variable.

Optimal splits and rules are created to increase homogeneity of the groups. These splits are determined according to different classification indices, depending on the model used. The basic classification tree, CART (Classification and Regression Tree), uses the Gini impurity (Breiman et al., 1984). The Gini impurity is a measure of the frequency of incorrect labelling of a, from a set randomly chosen, element if it was randomly labeled according to the distribution of labels in the subset. The j48 (also called C4.5) model bases its splitting process on information gain, with the gain being the difference of information prior versus after the split (Quinlan, 1987, 1993). The C5.0 model is the more advanced version of the j48, with additional features such as boosting (explained below) (Kuhn and Johnson, 2013). C5.0 trees present several improvements that are likely to generate smaller trees. The global pruning procedure removes the sub-trees with a cost-complexity approach; sub-trees are removed until the error rate exceeds one standard error of the tree without pruning.

Bagging, i.e. bootstrap aggregation, belongs to the ensemble techniques (Breiman, 1996). A bootstrap sample of the original data is generated and an unpruned tree model is trained on each sample. For each model in the ensemble, a prediction is generated for a new sample and all these predictions are averaged to generate the prediction of the bagged trees. Through the aggregation process, the variance of the prediction is reduced, which makes the prediction thus more stable.

In the PART model, initially a pruned classification tree (j48) is created and the path through the tree with the largest coverage is determined (Frank and Witten, 1998). This path is added as a rule to the rule set and the training set samples covered by

[9] A simplified example is given in Appendix C.

this rule are removed from the dataset. This process is repeated until all training set samples are covered by a rule.

Boosted C5.0 models are created by sequentially fitting models and, at each iteration, the case weights are adjusted based on the accuracy of the sample's prediction (Kuhn and Johnson, 2013). Samples that are incorrectly classified receive more weight in the subsequent iteration and samples that are correctly classified less weight. This refers to giving the difficult-to-classify samples more weight until the algorithm identifies a model that correctly classifies these samples.

For C5.0, the importance of predictors is determined by assessing the percentage of training set samples that fall into all the terminal nodes after the split (Kuhn and Johnson, 2013). Thus, the predictor in the first split has an importance measurement of 100% as all training set samples are affected by this split.

An additional option of C5.0 constitutes the removal or winnowing of predictors (Kuhn and Johnson, 2013): the predictors determined to be important in an initial algorithm are used to create the final model. This is done be splitting the training set randomly in half and creating a tree to determine the importance of the predictors (the 'winnowing tree'). To determine the importance of the predictors, two reasonings are followed. (1) Predictors that are not in any split in the winnowing tree are considered unimportant. (2) The error rate of the tree is evaluated through the half of the training set samples that were not included to create the winnowing tree. In addition, the error rate is determined without each predictor and compared to the error rate when all the predictors are used. If the error rate without the predictor is higher than the overall error rate, the predictor is considered unimportant and is removed.

Decision trees are flow-chart like structures, which are thus easy to interpret. In addition, variable selection is implicitly performed by the algorithm. Variables that do not contribute to the homogeneity of the groups are not included in the tree, and are thus not considered important for the decision at hand. Another advantage of decision trees is that they do not require linearity relationship between variables.

For model comparison purposes, the dataset was partitioned in a training set and a test set (split ratio = 0.8), which were recursively resampled (n = 100), in order to evaluate the models.

To achieve the splitting of the data, multiple resampling techniques exist, which generally work in a similar manner. The training set serves to build and tune the model and the test set is used to determine the model's predictive power. This is repeated multiple times and the result is aggregated and summarised.

k-fold cross validation (CV) randomly splits the data into *k* blocks of roughly equal size. Each of these blocks is left out in turn, and the remaining *k*-1 samples are used to build the model. The held out block of data is predicted and the efficacy of these predictions is summarised. All the generated estimates of the prediction performance are averaged to get the overall resampled estimate. Repeated k-fold CV works in the same way but repeats the process multiple times. One refers to Leave-One-Out CV, when *k* is equal to the sample size. When randomly a set percentage of the data is left out, one speaks of Leave Group Out CV (LGOCV). The bootstrap sample is a random sample of the data taken with replacement. Thus, it is likely that a datapoint is represented more than once in a bootstrap sample. This bootstrap sample is used to train the model and the remaining, not in the sample, data points are used to predict.

The bias of the resampling technique is related to the hold out data. When holding out 50% of the data, the final performance estimate will be more biased than when holding out 10%. However, when holding out less data, the precision is lowered as each hold-out sample has less data to get a stable estimate of the performance of the model.

LGOCV was chosen as bias and variance properties are good and the computational costs are not large (Kuhn and Johnson, 2013).

> A correlation matrix was constructed, and the highly correlated variables (threshold ≥ 0.75) were removed. The performance of the models was assessed through ROC (*receiver operating characteristic*) curves and their corresponding area under the curve (AUC) values, sensitivity and specificity. The chosen classification algorithm was then applied to the complete dataset.

The ROC curve, a function of sensitivity and specificity, can be used for quantitive assessment of the model (Kuhn and Johnson, 2013). The sensitivity of the model, also called true positive rate, is the rate of positives that are correctly identified as such. The specificity, also called the true negative rate, is the proportion of nonevent samples that are predicted as nonevents. The false-positive rate is defined as one minus the specificity. The ROC curve is generated by evaluating the true-positive rate, i.e. sensitivity, and the false-positive rate, across a continuum of thresholds. The model with the largest area under ROC curve would be most effective to explain the data.

Results and discussion

Descriptive analysis of the dataset Overall, the analysis rate of collected biological traces (i.e. the rate of biological traces submitted for analysis per collected traces) was .74, with .56 of biological traces analysed in a first batch. By comparison, for fingermarks and shoe marks, the analysis rates reached .90 (.87 and .93 respectively). The analysis decisions for fingermarks and shoe marks were not studied in detail, as around 90% turn-around was determined and these analyses were performed in-house. The main reasons for the non-analysis of fingermarks or shoe marks were quality and/or redundancy: either the trace was considered to be of poor quality or the trace existed already in the case and was thus not further processed. Due to the high analysis rates for these types of traces, the variables *Number of collected fingermarks* and *Number of collected shoe marks* can be considered to be equivalent to the *Number of analysed fingermarks* and *Number of analysed shoe marks*.

Within the given dataset, the number of collected shoe marks lies at 70, with 65 analysed (93%), and 31 fingermarks were collected and 27 analysed (87%). Similarly to the results obtained previously in the study of the commercial burglaries, most triaging occurs for biological traces. In Figure 6.8, the box plots of the analysis rates of biological traces, shoe marks and fingermarks are shown.[10] The median of all three is equal to 1. However, for shoe marks and fingermarks, both the first and the third quartile are also 1, hence only a very few values lie outside this value. Although shoe marks and fingermarks were considered to be of poor quality at the moment of decision-making regarding analysis, they were collected because the quality assessment at the crime scene was inconclusive. Biological traces, on the

[10] The representation through violin plots is misleading for these small samples, which can be seen in Appendix D Figure D.1.

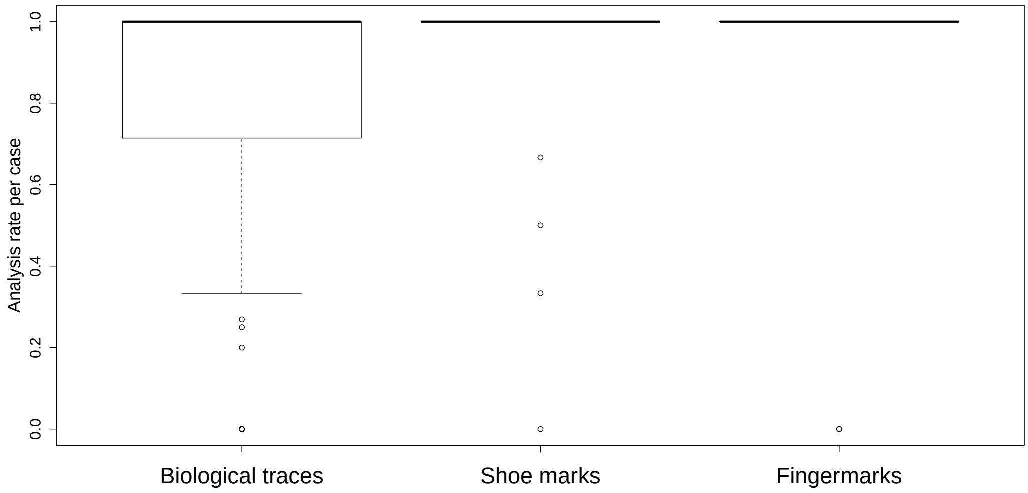

Fig. 6.8.: Box plots to compare of the distributions of the analysis rates of biological traces, shoe marks and fingermarks.

other side, showcase a more broad range of analysis strategy and thus triaging takes place.

Trace attrition The general trace attrition rates for biological traces are summarised in Figure 6.9. 74% of collected biological traces are analysed, and 54% of collected traces generate a positive result (success rate of 73%), i.e. a DNA profile that can be compared either with the national DNA database or the profile of a known person. 24% of collected traces generate an individualisation (hit rate of 45%). Finally, 15% of the collected traces hit with the profile of an individual in the DNA database or the victim to yield a pertinent identification, corresponding to 61% of general hits. For recollection, this pertinent hit rate corresponds to hits with the suspect, or victim when these were obtained on suspect's clothing, for instance. In these cases, the hits can be considered pertinent, as they are potentially useful to the case.

In total, 6 victim hits out of 28 total victim hits can be considered useful. Indeed, these are cases where the victim's profile is found on objects retrieved from the suspect, and a link between both persons can thus be inferred. In the same sense, not all suspect hits are really useful. Out of 58 suspect hits, two can be considered useless: confirmation of the suspect's profile on clothing of the suspect himself.

When considering the violin plots, the analysis rate has a definite trend towards 1, as has been stated earlier. The first quartile (*Q1*) lies at .72, thus 75% of the data lie

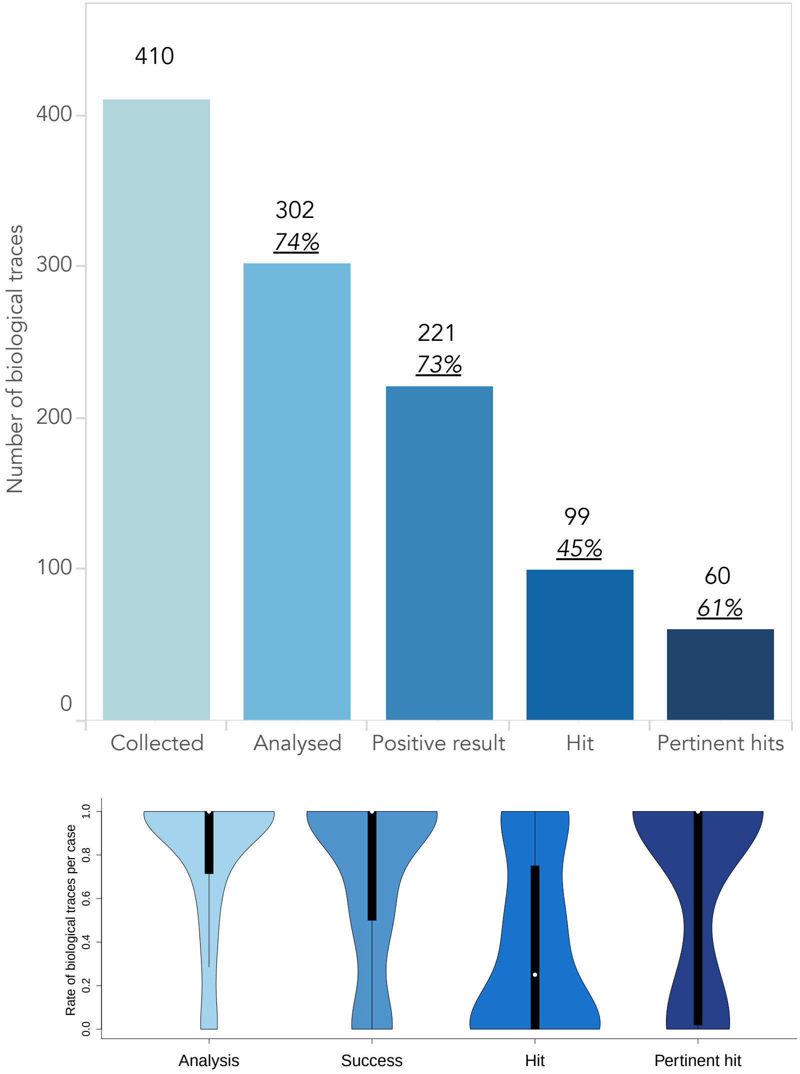

Fig. 6.9.: *Top*: Trace attrition from number of collected biological traces, analysed, those yielding a positive result, those generating a hit, to those generating a pertinent hit. In italic the average relative analysis, success, hit and pertinent hit rates. *Bottom*: Violin plots of the analysis, success, hit and pertinent hit rates per case.

above this value. For the success rate, the distribution is wider, and the first quartile (*Q1*) lies at .5, thus in 75% of cases, the success rate lies above .5. The hit rate is distributed very largely, and the median is at .25. Thus, in 50% of the cases, the hit rate is below .25. The distribution of the pertinent hit rate ranges from 0 to 1, with 75% of the data being above 0.

The first step of our study consisted of a descriptive statistical analysis of the raw data for each variable that considered the perspectives of both dependent variables: all the analysed traces (General set) and only the traces that were part of the first submitted batch (First batch analysis). Table 6.5 presents the breakdown of the analysed and non-analysed traces.

Comparison and selection of classification modelling Two groups of variables were identified as being correlated. The first group (indicated † in Table 6.5) was constituted of two variables from the physical dimension and the second group (indicated # in Table 6.5) of 5 variables from the utility dimension. From these groups, the least correlated variable(s) remain(s) for the construction of the models.

The correlation matrix is shown in Figure 6.10.

Different classification models were applied to the resampled training and the corresponding test sets. The application of different classification models aimed at assessing whether the simpler models could compare in terms of performance and accuracy with more complex ones. Overall, the performance values (AUROC; Area under ROC measured through a combination of specificity and sensitivity) were very good for all the models, especially with the general set (see Figure 6.11). The best classification performance of our data, i.e. highest AUROC values, were obtained with the boosted trees (mean of AUROC: 0.9729) for the general dataset, and the boosted C5.0 trees (mean of AUROC: 0.8299) for the first batch analysis.

As the performance of the simpler C5.0 single decision tree model compares well to the more complex models, the C5.0 single tree decision model[11] was finally chosen for further analysis (mean of AUROC: 0.9328 respectively 0.7556), as

[11] *Addendum:* Winnowing option used.

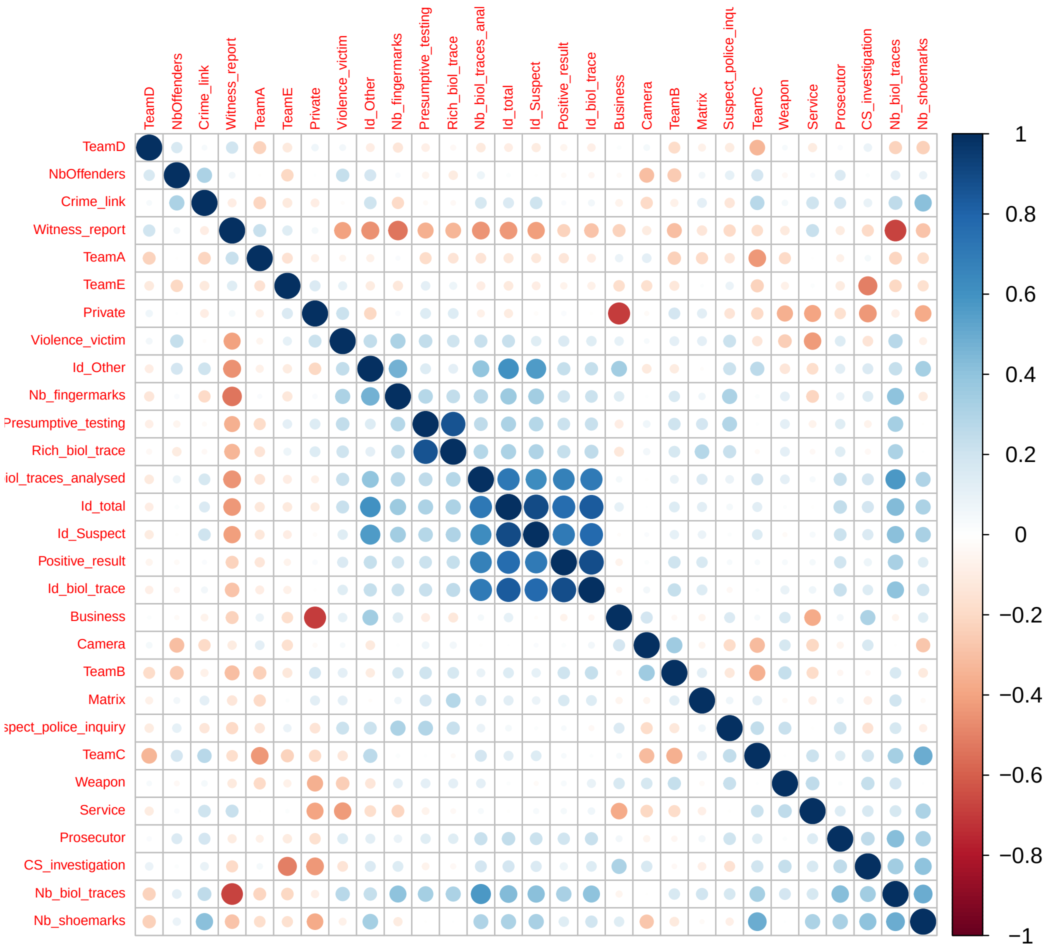

Fig. 6.10.: Correlation matrix showing the correlation between the dependent variables.

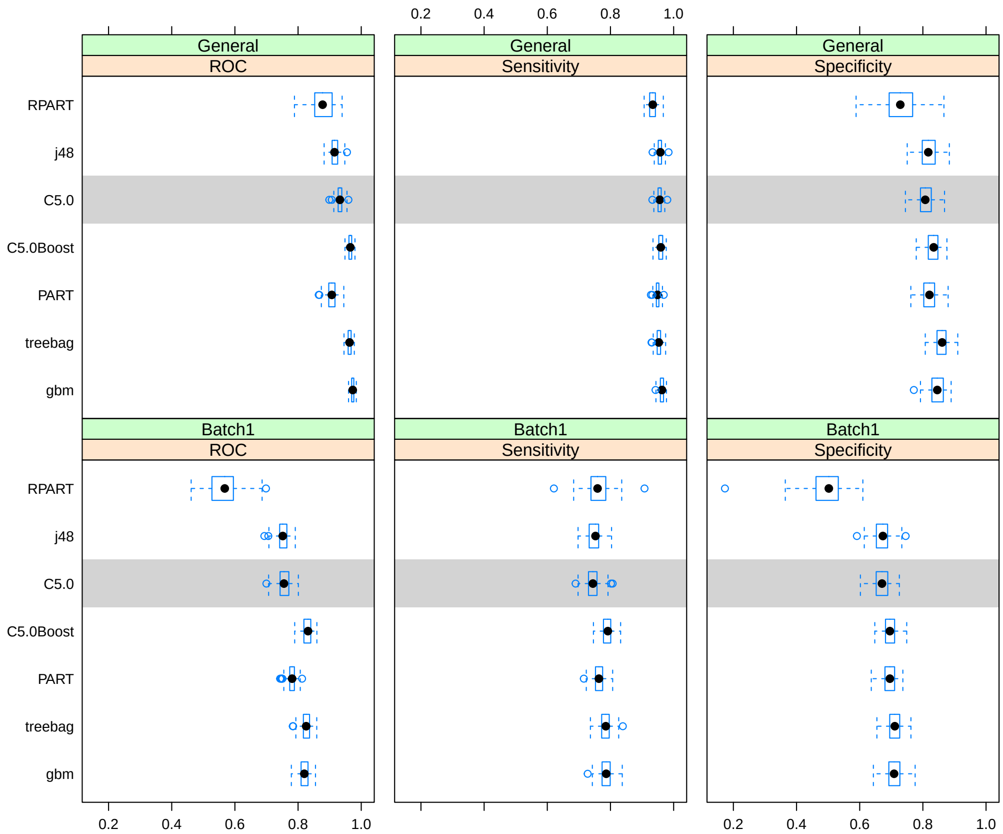

Fig. 6.11.: Comparison of performance values (AUROC, sensitivity and specificity values) for all tested models using resampled training and test sets (n = 100) for general set and first batch analysis. The highlighted models were chosen for classification modelling, as a compromise between good performance results and simplicity of interpretation.

Tab. 6.5.: Descriptive statistics on the number of trace analyses and non-analyses (N = 410). Two groups of variables were identified as being correlated (indexed with † and #); of these groups only those marked with (*) remain for the construction of the models.

Variable	n	General set		First batch analysis	
		Analysis of trace n (%)	Non analysis of trace n (%)	Analysis of trace n (%)	Non analysis of trace n (%)
Total[12]	410	302	108	229	181
Strategic					
Type of intervention					
Crime scene intervention	353	258 (73.09)	95 (26.91)	187 (52.97)	166 (47.03)
Objects brought to lab	57	44 (77.51)	13 (22.81)	42 (73.68)	15 (26.32)
Prosecutor in charge of the case					
yes	345	247 (71.59)	98 (28.41)	184 (53.33)	161 (46.67)
no	65	55 (84.62)	10 (15.38)	45 (69.23)	20 (30.77)
Inspector in charge – Team					
a	91	79 (86.81)	12 (13.19)	63 (69.23)	28 (30.77)
b	67	31 (46.27)	36 (53.73)	27 (40.30)	40 (59.70)
c	162	113 (69.75)	49 (30.25)	76 (46.91)	86 (53.09)
d	60	53 (88.33)	7 (11.67)	39 (65.00)	21 (35.00)
e	30	26 (86.67)	4 (13.33)	24 (80.00)	6 (20.00)
Number of collected biological traces					
1	36	33 (91.67)	3 (8.33)	33 (91.67)	3 (8.33)
2	48	36 (75.00)	12 (25.00)	31 (64.58)	17 (35.42)
3	27	23 (85.19)	4 (14.81)	20 (74.07)	7 (25.93)
4	12	7 (58.33)	5 (41.67)	3 (25.00)	9 (75.00)
5	34	24 (70.59)	10 (29.41)	23 (67.65)	11 (32.35)
> 5	253	179 (70.75)	74 (29.25)	119 (47.04)	134 (52.96)
Immediate					
Target					
Business	163	121 (74.23)	42 (25.77)	91 (55.83)	72 (44.17)

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[12] This line has been added compared to the version in the article.

Tab. 6.5 – *Continued from previous page*

Variable	n	General set		First batch analysis	
		Analysis of trace	Non analysis of trace	Analysis of trace	Non analysis of trace
		n (%)	n (%)	n (%)	n (%)
Service	73	53 (72.60)	20 (27.40)	30 (41.10)	43 (58.90)
Private	174	128 (73.56)	46 (26.44)	108 (62.07)	66 (37.93)
Surveillance camera					
yes	102	71 (69.61)	31 (30.39)	57 (55.88)	45 (44.12)
no	308	231 (75.00)	77 (25.00)	172 (55.84)	136 (44.16)
Witness report					
yes	335	261 (77.91)	74 (22.09)	202 (60.30)	133 (39.70)
no	75	41 (54.67)	34 (45.33)	27 (36.00)	48 (74.00)
Armed robbery					
yes	272	190 (69.85)	82 (30.15)	136 (50.00)	136 (50.00)
no	138	112 (81.16)	26 (18.84)	93 (67.39)	45 (32.61)
Violence against victim					
yes	214	144 (67.29)	70 (32.71)	114 (53.27)	100 (46.73)
no	196	158 (80.61)	38 (19.39)	115 (58.67)	81 (41.33)
Number of offenders					
1	91	63 (69.23)	28 (30.77)	57 (62.64)	34 (37.36)
2	134	107 (79.85)	27 (20.15)	82 (61.19)	52 (38.81)
3	157	109 (69.43)	48 (30.57)	76 (48.41)	81 (51.59)
> 3	28	23 (82.14)	5 (17.86)	14 (50.00)	14 (50.00)
Number of collected shoe marks					
0	150	121 (80.67)	29 (19.33)	103 (68.67)	47 (31.33)
1	89	53 (59.55)	36 (40.45)	37 (41.57)	52 (58.43)
2	66	39 (59.09)	27 (40.91)	32 (48.48)	34 (51.52)
> 2	105	89 (84.76)	16 (15.34)	57 (54.29)	48 (45.71)
Number of collected fingermarks					
0	324	262 (80.86)	62 (19.14)	198 (61.11)	126 (38.89)
1	8	4 (50.00)	4 (50.00)	2 (25.00)	6 (75.00)
2	44	17 (38.64)	27 (61.36)	16 (36.36)	28 (63.64)
> 2	34	19 (55.88)	15 (44.12)	13 (38.24)	21 (61.76)

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Tab. 6.5 – *Continued from previous page*

Variable	n	General set		First batch analysis	
		Analysis of trace	Non analysis of trace	Analysis of trace	Non analysis of trace
		n (%)	n (%)	n (%)	n (%)
Physical					
Type of biological trace[†,*]					
"Rich" biological trace	91	43 (47.25)	48 (52.75)	30 (32.97)	61 (68.03)
Contact trace	319	259 (81.19)	60 (18.81)	199 (62.38)	120 (37.62)
Presumptive testing[†]					
yes	74	29 (39.19)	45 (70.81)	21 (28.38)	53 (71.62)
no	336	273 (81.25)	63 (18.75)	208 (61.90)	128 (38.10)
Matrix of the trace					
Propitious (≥ 0.5)	296	209 (70.61)	87 (29.39)	155 (52.36)	141 (47.64)
Non propitious (< 0.5)	114	93 (81.58)	21 (18.42)	74 (64.91)	40 (35.09)
Criminal					
Known crime link					
yes	63	54 (85.71)	9 (14.29)	26 (41.27)	37 (58.73)
no	347	248 (71.47)	99 (28.53)	203 (58.50)	144 (41.50)
Utility					
Suspect identification through police inquiry					
yes	76	33 (43.42)	43 (56.58)	26 (34.21)	50 (65.79)
no	334	269 (80.54)	65 (19.46)	206 (61.68)	128 (38.32)
Number of biological traces analysed previously in the case[#,*]					
0	256	232 (90.63)	24 (9.37)	NA	NA
> 0	154	70 (45.45)	84 (54.55)	NA	NA
Positive result available[#,*]					
yes	107	29 (27.10)	78 (72.90)	NA	NA
no	303	273 (90.10)	30 (9.90)	NA	NA

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Tab. 6.5 – *Continued from previous page*

Variable	n	General set		First batch analysis	
		Analysis of trace	Non analysis of trace	Analysis of trace	Non analysis of trace
		n (%)	n (%)	n (%)	n (%)
Identification available through biological trace analysis#					
yes	89	22 (24.72)	67 (72.28)	NA	NA
no	321	280 (87.23)	41 (12.78)	NA	NA
Identification available through other traces					
yes	51	23 (45.10)	28 (54.90)	11 (21.57)	40 (78.43)
no	359	279 (77.72)	80 (22.28)	218 (60.72)	141 (39.28)
Identification available total#					
yes	116	42 (36.21)	74 (63.79)	NA	NA
no	294	260 (88.44)	34 (11.56)	NA	NA
Suspect identification available before analysis#					
yes	101	35 (34.65)	66 (65.35)	NA	NA
no	309	267 (86.41)	42 (13.59)	NA	NA

the outcome is more easily interpretable. This choice was adopted as the main aim of the study was to understand and model the decision process and we are not striving for excellent predictive power. Another advantage of the C5.0 decision tree model is that a visualisation of the model can be extracted, as opposed to the bagged or boosted trees for instance.

General set of data Of the 25 independent variables that were considered, 9 were used to construct the model (see Figure 6.13). Thus, these 9 factors contribute to the decision to analyse a trace, in the sense that the splits created by these factors lead to the constitution of smaller, more homogeneous groups. In the first model, considering all the analysed traces, these are mainly variables related to previously available information, such as the factor that a positive result is already available within the specific case (which is correlated to other factors involving previous knowledge, as shown in Table 6.5), or that the suspect has been identified through police inquiry before analysis. However, forensic factors also contribute to the decision to analyse a trace, such as forensic intelligence and the number of collected biological traces. Furthermore, the decision appears to also depend upon individuals as the team of investigators in charge of the case influences the model.

Consideration of previous results It is interesting to emphasise that factors including previous information affect the decision to analyse a trace. Thus, the decision is not solely based on purely qualitative factors such as the type of biological trace. The knowledge of traces and of their analysis outcomes plays a significant role. The first factor is the knowledge about a previous positive result (a DNA profile suitable for comparison) already available within the specific case (node 1, Positive_result in Figure 6.13); hence, crime scene investigators take into account the results of previous analyses performed in the same case in their decision to analyse a biological trace. As this is the model for the "looking back" scenario, it is not surprising that some traces remain unanalysed when others have delivered a positive result. In a case with multiple biological traces, some traces might have delivered a usable profile or even an identification, hence the analysis of the remaining traces becomes less prone to provide new, useful information, and will thus not be performed. However, it needs to be emphasised that this positive result did not necessarily lead to an identification of a suspect. These two variables are correlated, and as a consequence, the latter was not included in the model, however, they are not fully equivalent.

The results of the influence of this variable on the analysis, success, hit and pertinent hit rates are shown in Figure 6.12. When no positive result is available, 90% of collected biological traces are analysed. Whereas, when a positive result is already available, the analysis rate is at 27% of collected traces. This result highlights the consideration of previous analyses and their outcomes in the subsequent analysis strategy. When no positive result is available, the success rate lies at 75% of analysed traces. When a positive result is available, the success rate is at 54% of analysed traces. This would mean that traces with higher success rates are chosen at first, when no positive result is available thus far. The hit rates on both sides are comparable, 45 versus 47 %. However, the numbers in the left box, when a positive result is available, are relatively small, thus care must be applied when interpreting these results.

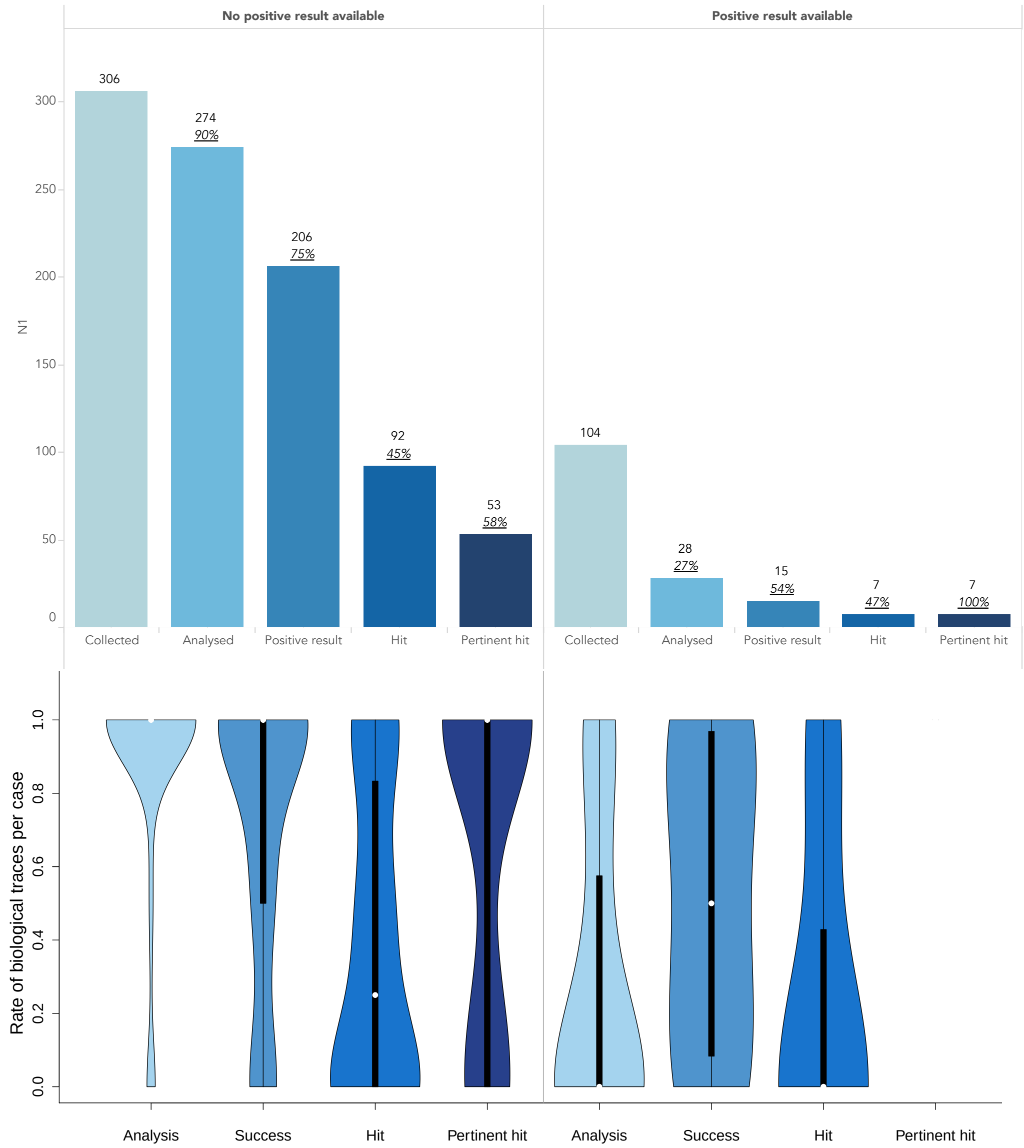

Fig. 6.12.: Trace attrition considering the knowledge of a previous result in the case. *Top*: From the number of collected biological traces, analysed, those yielding a positive result, those generating a hit, to those generating a pertinent hit. In italic the average relative analysis, success and hit and pertinent hit rates. *Bottom*: Violin plots of the analysis, success, hit and pertinent hit rates per case.

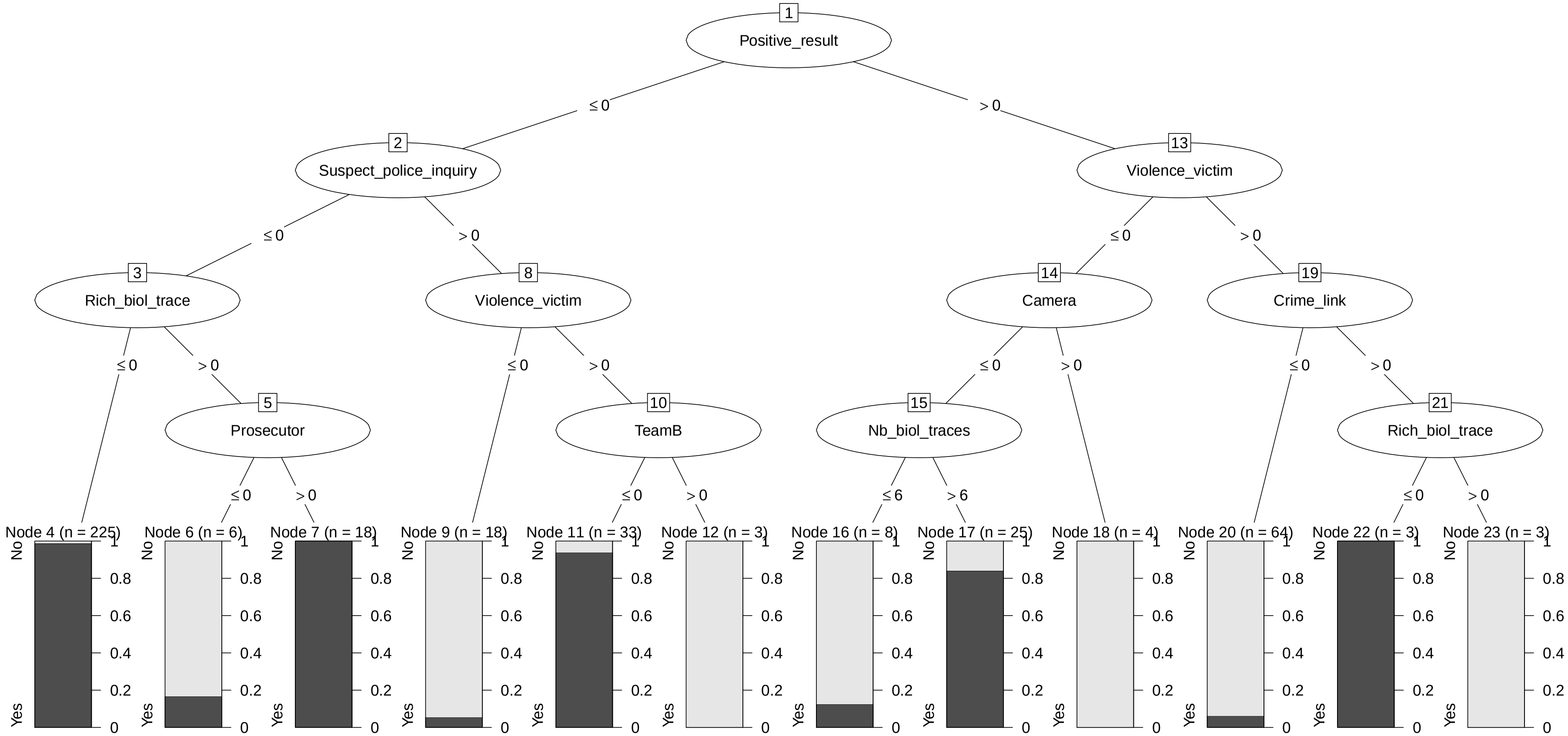

Fig. 6.13.: C5.0 decision tree model of the general data set. *Addendum*: The framed numbers correspond to node numbers. The darkgrey area indicates the proportion of analysed traces and the light grey area indicates the proportion of non-analysed traces.

Suspect identification through police enquiry When 'no positive result' was available (i.e. either no DNA analysis has been performed, or, the result of the analysis did not yield a profile that is of sufficient quality to be used for comparison), traditional police work was of importance (node 2, Suspect_police_inquiry in Figure 2). Indeed, this could be observed during the participant observation, as a crime scene investigator preferred to wait for the police inquiry and their results, before deciding whether to analyse a trace or not. These results contradict one of the predominantly mentioned reasons for analysing a trace, which was to build a case against the suspect (Mapes et al., 2015; Bitzer et al., 2015; Baskin and Sommers, 2010). In the studied forensic unit, this reason could not be corroborated. If a suspect was identified prior to the analysis, the analysis rate of biological traces dropped (see Table 6.5). The main utility of the trace appears to be to gather intelligence rather than to produce evidence. The potential of a biological trace – by comparison with a reference database – to "provide" a name is widely understood. Contrary to the reasons found in the literature for the non-submission for analysis of a trace, the crime scene investigators exploited the trace's potential to "provide" a lead in the inquiry. Interestingly, the causal link appears to be in the opposite direction, compared to the studies that analysed the predictive effect of the presence of traces on arrest. It is not the presence of traces that is predictive of arrest, but arrest that is predictive of the analysis of traces.[13] Hence, it appears very likely that the crime scene investigators consider the utility of the clue, in context with the available information, to form their decision about the traces to analyse (Bitzer et al., 2015, 2016).

As was previously noted, crime scene investigators decide to analyse traces in regards to their utility of identification; when no suspect identification had been achieved thus far in the case (STI), more traces are analysed (see Figure 6.13). This can also be shown in the trace attrition rates when comparing both states of the identification utility (Figure 6.14).

A priori, when the suspect(s) has (have) not been identified through police inquiry (STI), 81% of collected biological traces are submitted for analysis. When suspect(s) have been identified (SI), a mere 43% of collected biological traces are analysed. This difference can also be observed in the violin plots, showing the distribution of the analysis rates of biological traces per case in both situations. However, when

[13] *Addendum*: No amalgam of identification and arrest of a suspect was intended here. The arrest of a suspect includes, in addition to its identification, its localisation. However, the traces under scrutiny in this study, did not add value to the localisation of a suspect.

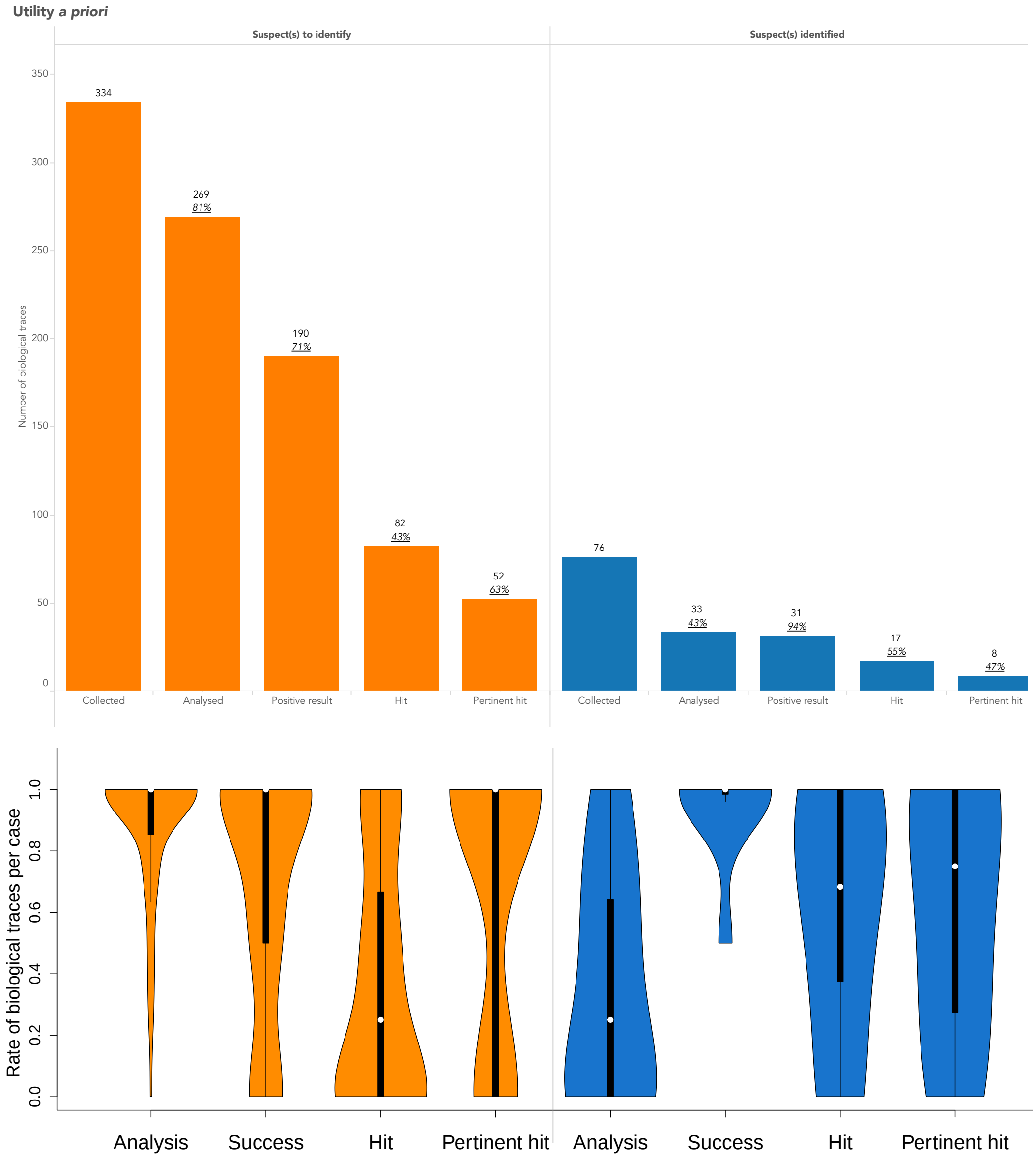

Fig. 6.14.: Trace attrition considering the utility *a priori*: no suspect identification before analysis or suspect identification. *Top*: From the number of collected biological traces, analysed, those yielding a positive result, those generating a hit, to those generating a pertinent hit. In italic the average relative analysis, success and hit and pertinent hit rates. *Bottom*: Violin plots of the analysis, success, hit and pertinent hit rates per case.

comparing the success rates, a big difference can be observed: in the first case, 71% of analysed traces yield a positive result, whereas in the second case, this rate increases to 94% of analysed traces. Thus, the traces they choose for analysis, when the case is considered solved before analysis (SI), are prone to yield a comparable profile (of the victim or the alleged offender). In both cases, the distribution of the success rates are similarly distributed towards 1. When going one step further, and looking at the hit rates, in the first case 43% of positive results generate a hit compared to 55% in the second case. The identification of a suspect within the same case influences the probability of yielding a hit. A pertinent hit is yielded for 63% of hits when the suspect still needs to be identified. However, when the suspect has already been identified, the pertinent hit rate lies at 47% of hits.

The 8 traces (from 5 cases) that yield a pertinent hit when a suspect had been identified previous to the analysis have thus an expected utility different from identification. The inferred expected utility are in four cases confirmation or reconstruction (three times the suspect's profile was of interest and once the victim's, objects linked to the actions of the crime) and once for implication determination. In the latter case, three offenders committed a robbery, of which one attacked the victim violently. These three offenders were quickly identified through police enquiry, however, it needed to be determined who performed the attacks against the victim.

When combining both variables, the knowledge of previous information and the suspect identification through police enquiry, the results shown in Figure 6.15 are obtained. When no positive result is available, and a suspect still needs to be identified (hence, no information regarding the identity of the suspect is available), 96% of collected biological traces are analysed. However, when the suspect has already been identified through police inquiry, the analysis rate drops down to 59%. Similarly, when a positive result is already available, the analysis rate is at 33% for STI cases and at 5% for SI cases. This result highlights again the predominant use of biological traces for identification purposes. In STI cases, when no positive result is available, the success rate lies at 73% of analysed traces. In SI cases, the success rate is at 94% of cases. This shows that the crime scene investigators choose less traces for analysis, but they are more likely to yield a positive result. In addition, they are more likely to yield a hit (53 compared to 43%). Indeed, in SI cases, a direct comparison with a reference sample from the suspect is possible, whereas, in STI cases, the only references available are through the database.

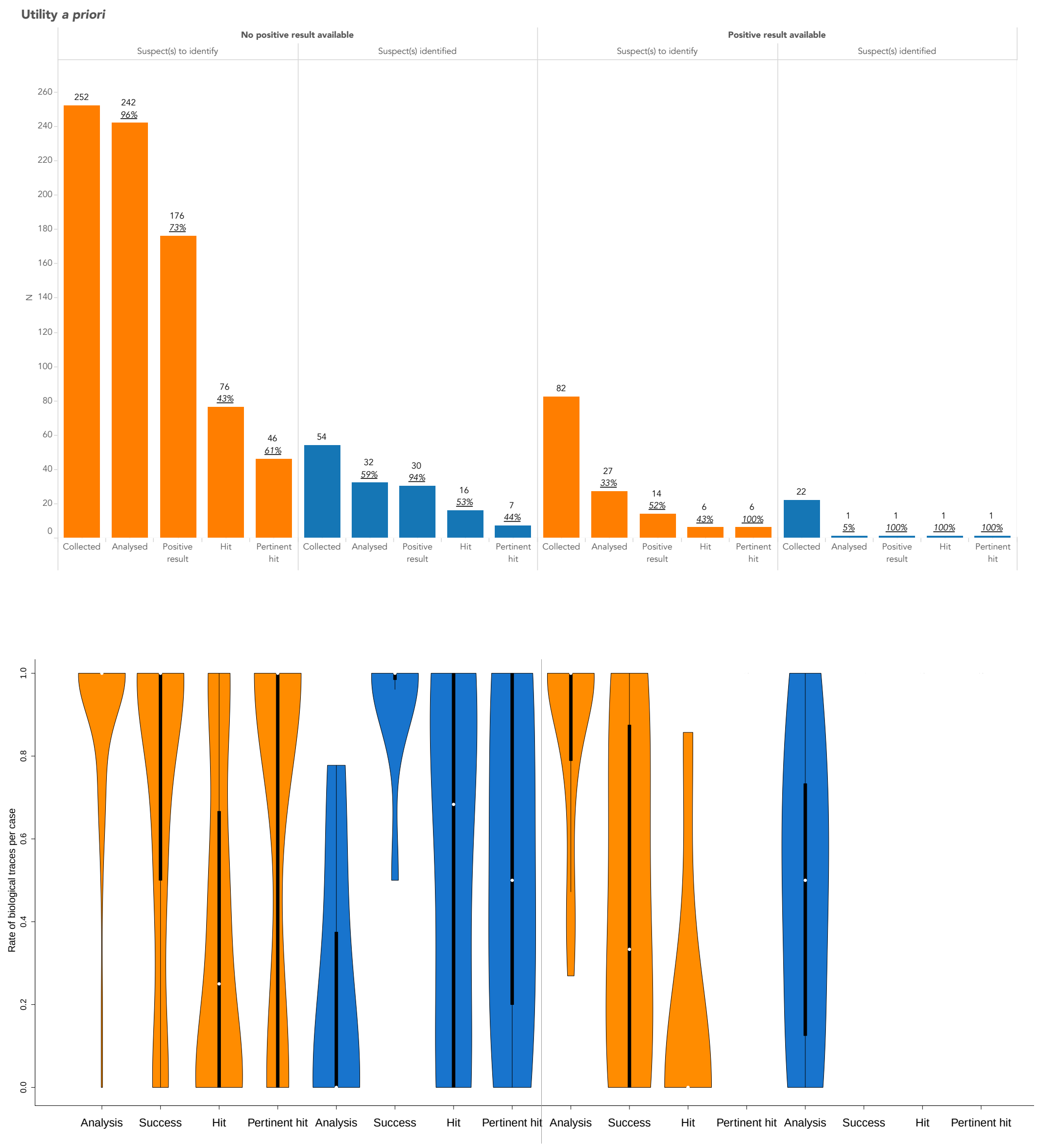

Fig. 6.15.: Trace attrition considering the utility *a priori*: no suspect identification or suspect identification, considering the knowledge of a previous result in the case. *Top*: From the number of collected biological traces, analysed, those yielding a positive result, those generating a hit, to those generating a pertinent hit. In italic the average relative analysis, success and hit and pertinent hit rates. *Bottom*: Violin plots of the analysis, success, hit and pertinent hit rates per case.

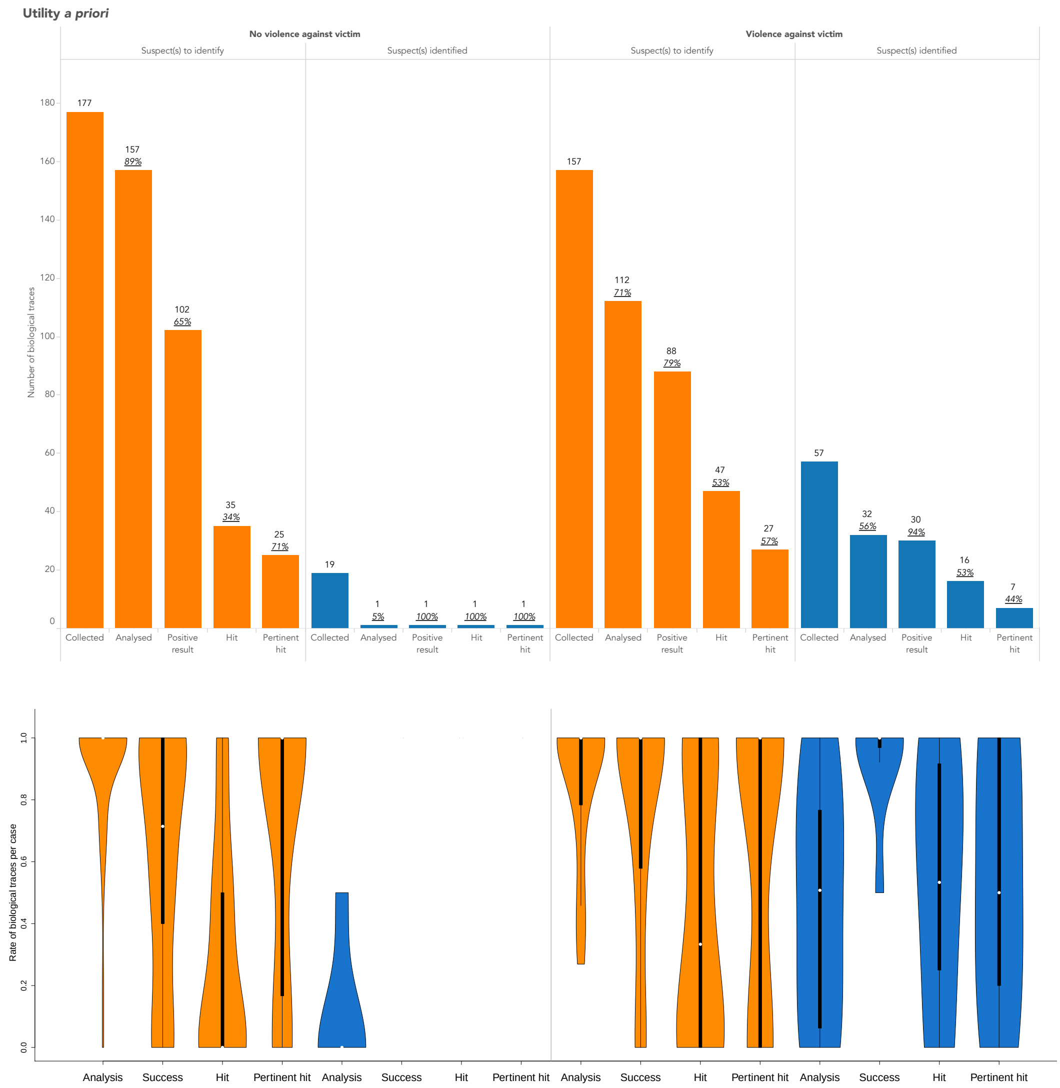

Fig. 6.16.: Trace attrition considering the utility *a priori*: no suspect identification before analysis or suspect identification, considering the presence or absence of violence against the victim. *Top*: From the number of collected biological traces, analysed, those yielding a positive result, those generating a hit, to those generating a pertinent hit. In italic the average relative analysis, success and hit and pertinent hit rates. *Bottom*: Violin plots of the analysis, success, hit and pertinent hit rates per case.

In addition to the knowledge of the identity of the suspect, this difference in analysis strategy could be explained by the seriousness of the case, which can be visualised through the presence of violence against the victim in the case (Figure 6.16). In SI cases, when no violence was applied to the victim, only 1 trace was analysed (corresponding to 5% of collected traces). However, when the victim was hurt, 56% of traces were analysed, although the suspect(s) had already been identified in the case. Again, this difference can be seen in the distribution of the analysis rates per case, in the violin plots of Figure 6.16. These results showcases the use of traces for their identification potential, in cases without violence. When it is a more serious case (i.e. the victim got hurt), the biological traces are also used for reconstruction or confirmation reasons. For SIT cases, the difference in analysis rate is not as pronounced, however, the trend is in the opposite direction. When violence was applied, 71% of traces were analysed, whereas, when no violence was applied, 89% of traces were analysed. According to the results from the decision tree modelling (Figure 6.13), if the suspect was unknown a priori, then the fact that there was violence against the victim did not influence the analysis rate.

Type of biological trace / Presumptive testing The descriptive model highlights that contact traces are preferably chosen for analysis over "rich" biological traces (nodes 3 and 21, Rich_biol_trace in Figure 6.13). At first, this finding appears counterintuitive as "rich" biological traces are more likely to yield a positive result in purely analytical terms. This is also contradictory to some of the analysis strategies in place: often the type of biological trace is the triaging factor (e.g. "rich" biological traces are preferably chosen for analysis over contact traces) in order to maximise the rate of profiles suitable for comparison (Mapes et al., 2015), more often than not in response to financial pressure. However, when looking at the case level and the information conveyed by the traces, the preference for contact biological traces makes a lot of sense. The reason for this seems to be that if "rich" biological traces are found (blood or saliva in these cases), the investigators inferred that these traces more likely originated from the victim (who was hurt in some cases) and are thus of lower utility to their case. By consequence, and very logically, they were not submitted for analysis. Furthermore, on recovered bottles or cans, the investigators infer the presence of saliva without performing presumptive testing. As the results of these tests directly define the assertion of presence of a "rich" biological trace, in such situation this latter variable was coded as 1 for Rich_biol_trace but 0 for Presumptive_test.

In like manner, it is suggested to focus on the quantity of DNA present in biological traces as a decision factor in the decision to analyse a trace (Mapes et al., 2016). However, as noted by the authors, the decision whether to analyse a trace or not should not solely be based on this factor, but the seriousness of the case needs also to be taken into account.

One of the conditions outlined in the guideline in place at the time of the study at the forensic unit under scrutiny is that presumptive testing has to be performed on biological traces that one suspects to be 'rich', before submitting them for analysis. In all but one case, the presumptive test performed was positive. The very small negative rate indicates that the presumptive test is performed only for cases where the crime scene investigators already strongly believe that a 'rich' biological trace is present. The majority of the traces, where the crime scene investigators assume a 'rich' biological trace, but do not perform the presumptive testing, concerns bottles or balaclava, which are objects with high probability of finding a biological trace, and thus, extracting a profile.

The majority of the traces that were tested for presence of a 'rich' biological trace but that were not submitted for analysis, was mostly swabs of presumably blood traces. As earlier mentioned, this could be explained by the inference of the victim being at the source of these traces due to the (inferred or reported) course of events of the case.

The data however show quite the opposite result compared to what is requested in the guidelines (see Figure 6.17). When presumptive testing was performed on a collected biological trace, the trace was, in the majority of cases, not submitted for analysis (39% of traces with presumptive testing were submitted for analysis). Whereas, for traces that were not tested previously, 81% of traces were submitted for analysis. Not surprisingly, the traces that were tested for being a 'rich' biological trace, yielded in 93% of cases a positive result (as most presumptive tests were positive). However, a good 71% of traces, without presumptive testing, yielded a positive result as well. Thus, the difference in success rate exists but is not as emphasised as the policy-makers assert. When a presumptive test was performed, 70% of positive results led to a hit, whereas when no presumptive test was performed, a hit rate of 41% could be observed. However, in both situations, about 60% of these hits were pertinent hits. When the crime scene investigators choose 'rich' biological traces for analysis, and thus perform presumptive testing, it is more likely to yield a hit than

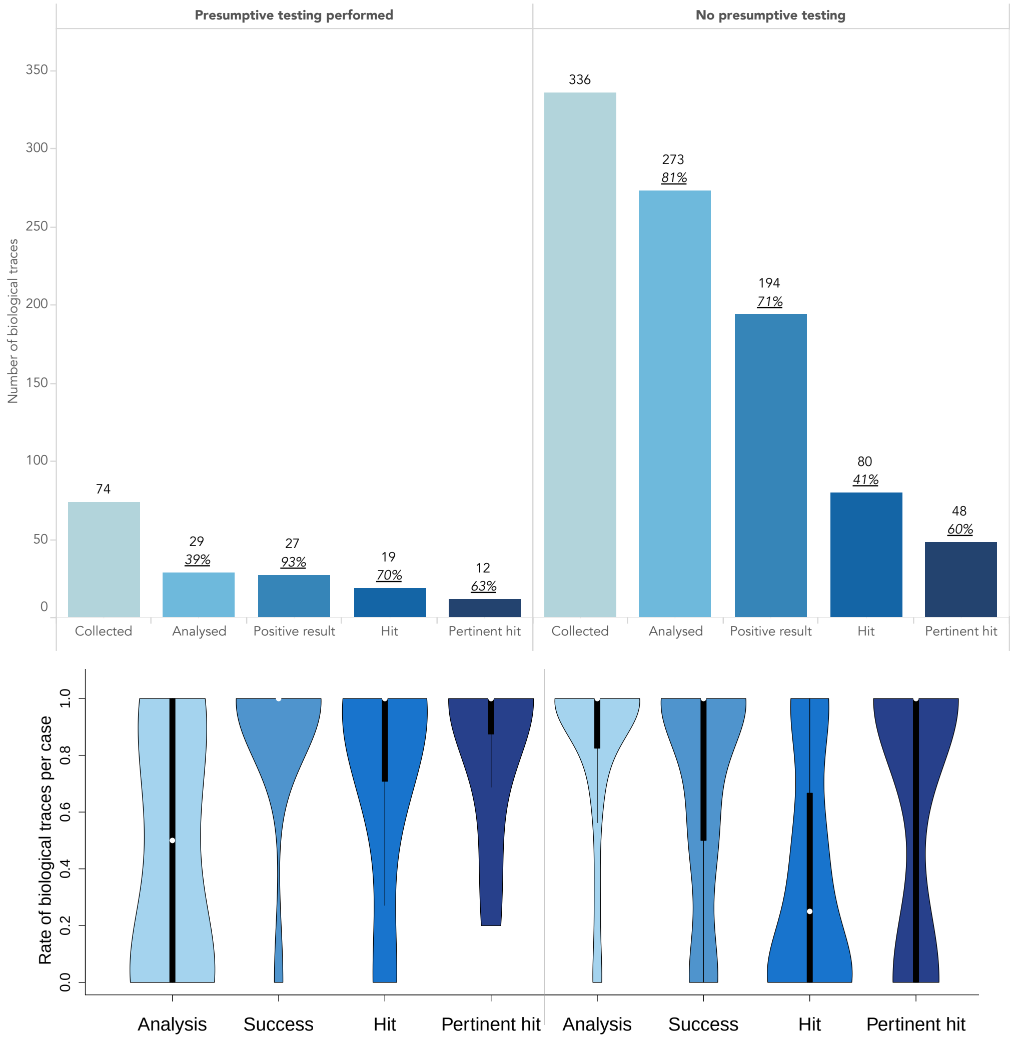

Fig. 6.17.: Trace attrition considering the performance of a presumptive testing prior to analysis. *Top*: From the number of collected biological traces, analysed, those yielding a positive result, those generating a hit, to those generating a pertinent hit. In italic the average relative analysis, success and hit and pertinent hit rates. *Bottom*: Violin plots of the analysis, success, hit and pertinent hit rates per case.

when no presumptive testing is performed. However, these hits are not more often pertinent hits.

The differences here must be considered with care, as the number of traces with performed presumptive testing is limited (N = 74) and thus the numbers of analysed traces, those yielding a positive results, and so on, are even lower. In addition, it must be noted that the absence of a performed presumptive test does not necessarily mean that it is a contact trace. It has solely not been confirmed that it is a 'rich' biological trace.

Prosecutor in charge In inquisitorial justice systems, the collaboration between the police and a 'prosecutor' is of high importance. This is because prosecutors have a broad range of competencies in deciding how investigations are conducted, and to commission expertise and analysis. As noticed during the participant observation, the involvement of a prosecutor was perceived very differently between the crime scene investigators. One crime scene investigator decided to analyse 3 out of 4 recovered biological traces in "priority mode" (analysed the same day as the others, but first on the list), in order to be able to quickly give the prosecutor results, and advice on the utility of the first 3 traces versus the fourth one, which he considered irrelevant. Other crime scene investigators work in close cooperation with the prosecutor and the decision about which traces to analyse arises though a collaborative approach. In the explicative model, the predictor Prosecutor is only important when no other results or police inquiry information are available, and when it is a "rich" biological trace. When the prosecutor is in charge of the case, and also of the financial part of the analyses, then all the biological traces are analysed. When there is no prosecutor in charge of the case, the proportion of analysed traces is much smaller. The same explanation as previously mentioned could be given: the prosecutor decides to analyse "rich" biological traces that the investigator inferred originated from the victim. At node 7, 17 out of 18 biological trace analyses resulted in a positive result, out of which 8 delivered a match with a suspect. The remaining 9 did not provide a match with the database, however, the victim cannot be excluded as being at the source of these traces, as a reference profile was not necessarily collected, analysed and compared.

Knowledge of crime link Crime intelligence appears to play a role in the decision to analyse a trace in certain situations (node 19, Crime_link in Figure 6.13). During the participant observation, it could be determined that the knowledge of a link with another crime would influence the decision to attend

Tab. 6.6.: Trace attrition from collection to number of traces generating a hit with a suspect of all types of offences registered in the database of the forensic unit from 2011 to 2013.

	Number of biol. traces	Rate compared to collected (%)	Relative rate (%)
Collected	8,010	-	-
Analysed	6,158	77	77
Positive result	3,380	42	55
Hit	1,471	18	44
Hit (suspect)	1,318	16	90

the scene, but also the analysis of traces. Indeed, a police investigator contacted the forensic unit in order to get information about traces that remained for analysis in the linked cases.

Matrix profile frequency in time In addition to considering the variables that have been included in the decision tree, it is also noteworthy to emphasise the variables that were excluded by the algorithm, as no additional information would have been provided by the inclusion of these variables. One factor that is often used in analysis strategies is the matrix on which the trace was deposited, and hence the likelihood of obtaining a positive result from such a matrix. This variable was not considered important in the decision tree for the general dataset. Hence, the decision to analyse a trace is not influenced by this variable. It needs to be highlighted here, that most of the figures for the probability of obtaining a positive result are stable throughout the analysed period.[14] However, for some matrices, it seems to be very difficult to make the right choice (decide for the analysis of that particular trace when the matrix is propitious for yielding a positive result), as the probability of obtaining a positive result varies a lot.

The variation of the frequency of obtaining a positive result over time will be scrutinised in detail. For this part of the study, all biological traces registered in the database of the forensic unit for all types of cases between 2011 and 2013 were used to obtain figures for the frequency of yielding a positive result according to the matrix (see Table 6.6). For this study, it was not possible to evaluate the pertinence of all the hits as the necessary details of information were missing, thus, only suspect hits are considered.

[14] *Addendum:* Here, we refer to the averaged value of success rates for the 4 trimesters previous to the analysis of the trace in question. Through this aggregation, less variation is observed.

Success rate Biological traces are often chosen for analysis based on the matrix they were recovered from (Pitteloud, 2014; Mapes et al., 2015). Statistical analysis of the success rates according to different matrices is used to set up a priority list of matrices which is supposed to give the crime scene investigators a guideline when choosing traces for analysis. The codification of traces used at the forensic unit of the canton Vaud is maintained, as afterwards, it is not possible to re-codify the matrices for all traces. This codification induces some uncertainties, which can not be resolved: for instance, what matrices are hidden behind 'contact traces'?. In addition, this codification involves both *physical* and *situational* dimensions. 'Keys', for instance, form (always) a smooth surface, thus referring to the physical quality of the matrix. Whereas, the category 'floor' is a situational variable, and the physical quality of this category can be very diverse; from floor tile, over carpet floor, to wooden floor. However, a posteriori, it is impossible to reorder the traces into a purely physical or purely situational dimension.

When determining the evolution over time of the success rates depending on the matrices of the traces, two groups can be formed (see Figure 6.18):

stable ($\triangle$ success rate $\leq$ 0.4) Floor, cigarette ends, bottle, human skin, clothing, others, vehicles, window, tools, contact traces.

variable ($\triangle$ success rate $>$ 0.4) Box, computer, cutting objects, cutlery, door handles, fabric, firearms, food, glasses, gloves, handles, jewellery, keys, paper, powdered traces, ropes, safe, shoes, tape, telephone.

At the top are some matrices that are quite stable over time regarding their frequency of obtaining a positive result, i.e. a DNA profile that can be compared. However, only 10 of the overall 30 matrices fall into that category. 'Tools' for instance fall into the first category, but are always on the lower end of the scale: the results vary between 0.21 and 0.45 in terms of success rate. Similarly, 'cigarette ends' give reliably good results (between 0.67 and 1).

The matrix category 'Bottle' showcases an increasing trend in success rate, accompanied with a mirrored, inverse, trend in analysis rate (see Figure 6.19). It can be hypothesised that this increase in success rate is influenced by the routine application of presumptive testing for potentially 'rich' biological traces, and/or the implementation of the new analysis technique in 2012 (Milon, 2013). However, this second

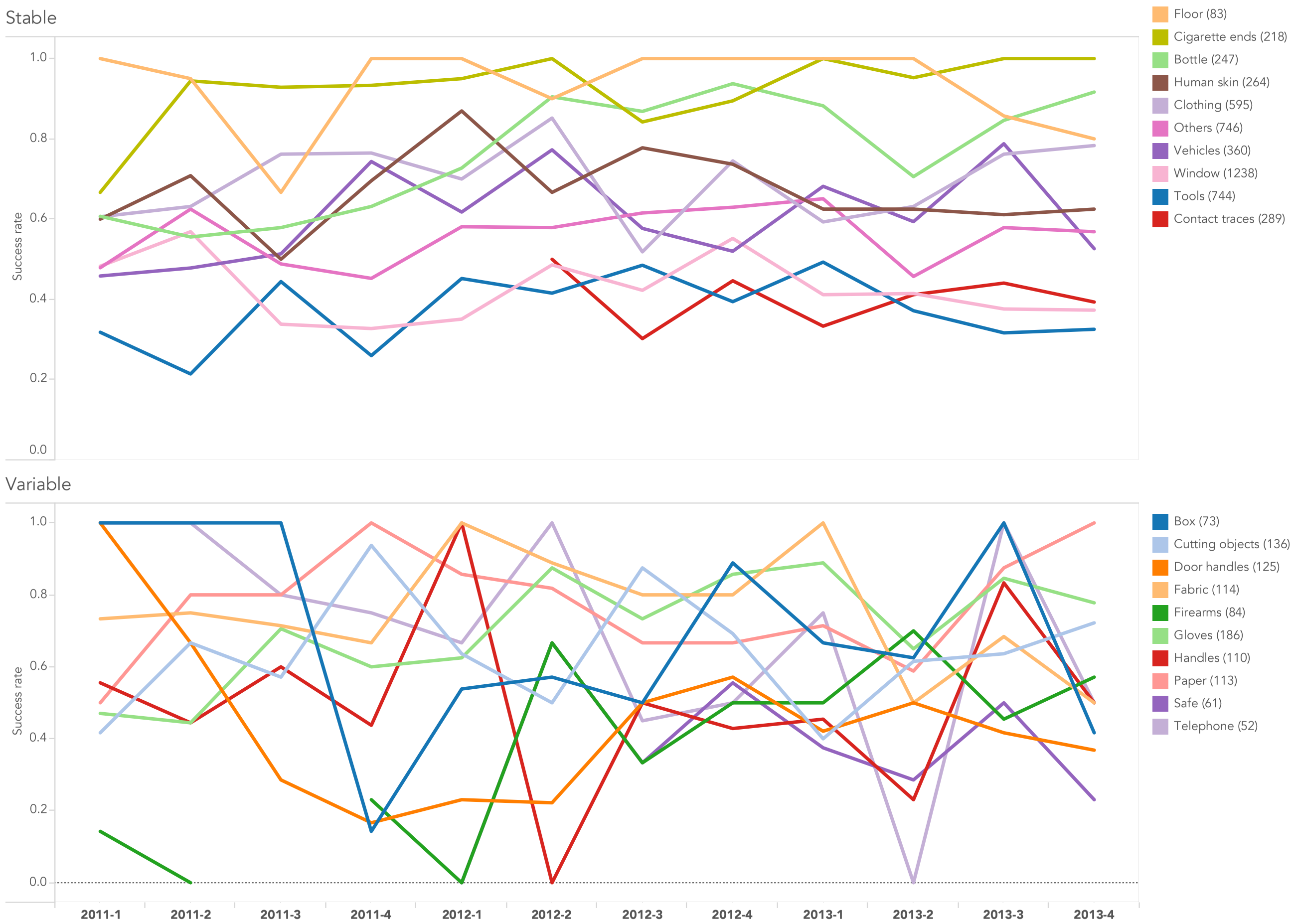

Fig. 6.18.: Frequency of obtaining a useable profile from a biological trace analysis depending on matrix over time in trimesters. *Top:* The matrices with stable frequency over time in trimesters. *Bottom:* Matrices with variable frequency over time in trimesters (only 10 of the 20 matrices in this group are represented here). In parentheses is the number of analysed biological traces per matrix.

point would also influence the results for all other matrices, which can however not be observed. A similar, yet more variable, increasing trend can be observed for the matrix category ‘Gloves’. Here, another reason for this change in success rate can be conjectured to relate to a change in sampling procedure. None of these hypotheses could however be confirmed.

For the remaining 20 matrices, no clear trend can be observed (only 10 of these matrices are represented in Figure 6.18 (bottom), for more detail see Figures 6.20 and 6.21). Recognisably, the bottom graph is messy. For some of the matrices, the difference between two trimesters lies at 100%, e.g. ‘Handles’: 2012-1 100% versus 2012-2 0%. This variation must be considered in the light of the low number of analysed traces on handles for these periods of time (3 and 2, respectively).

Nonetheless, it emphasises the impossibility of founding any criteria on this factor, especially not on the average success rate, without considering its temporal changes (see Table 6.7). This implies that for 2 out of 3 matrices, the frequency of obtaining a positive result is highly variable, and thus, crime scene investigators can not reliably choose biological traces for analysis solely based on their matrix. Fortunately, as was shown in the decision tree models, this was not the case for robbery cases, as a multitude of other factors, including those related to utility, were also of importance when choosing the traces for analysis.

Success rate vs hit or hit (suspect) rate In addition to very variable success rates, a high success rate does not guarantee a high hit rate or hit (suspect) rate (see Figures 6.19, 6.20 and 6.21).

‘Clothing’, for instance, has a relatively high success rate (always equal to or above 0.5), however, the hit rate is very low and in addition, the hit (suspect) rate is variable. Similarly, ‘human skin’ has a stable high success rate, but a very variable hit rate. Most importantly, the yielded hits are, more often than not, not suspect hits. ‘Cigarette ends’ and ‘Gloves’ yield reliably positive results, the hit rate is however constantly low (below 0.5). When a hit is yielded though, it is a suspect hit.

‘Contact traces’ are often chosen for analysis, albeit, their success rate is constantly low. In addition, the hit rate is also low. However, when a hit is yielded, it always matches the suspect’s profile. It can not be determined if these suspect hits are

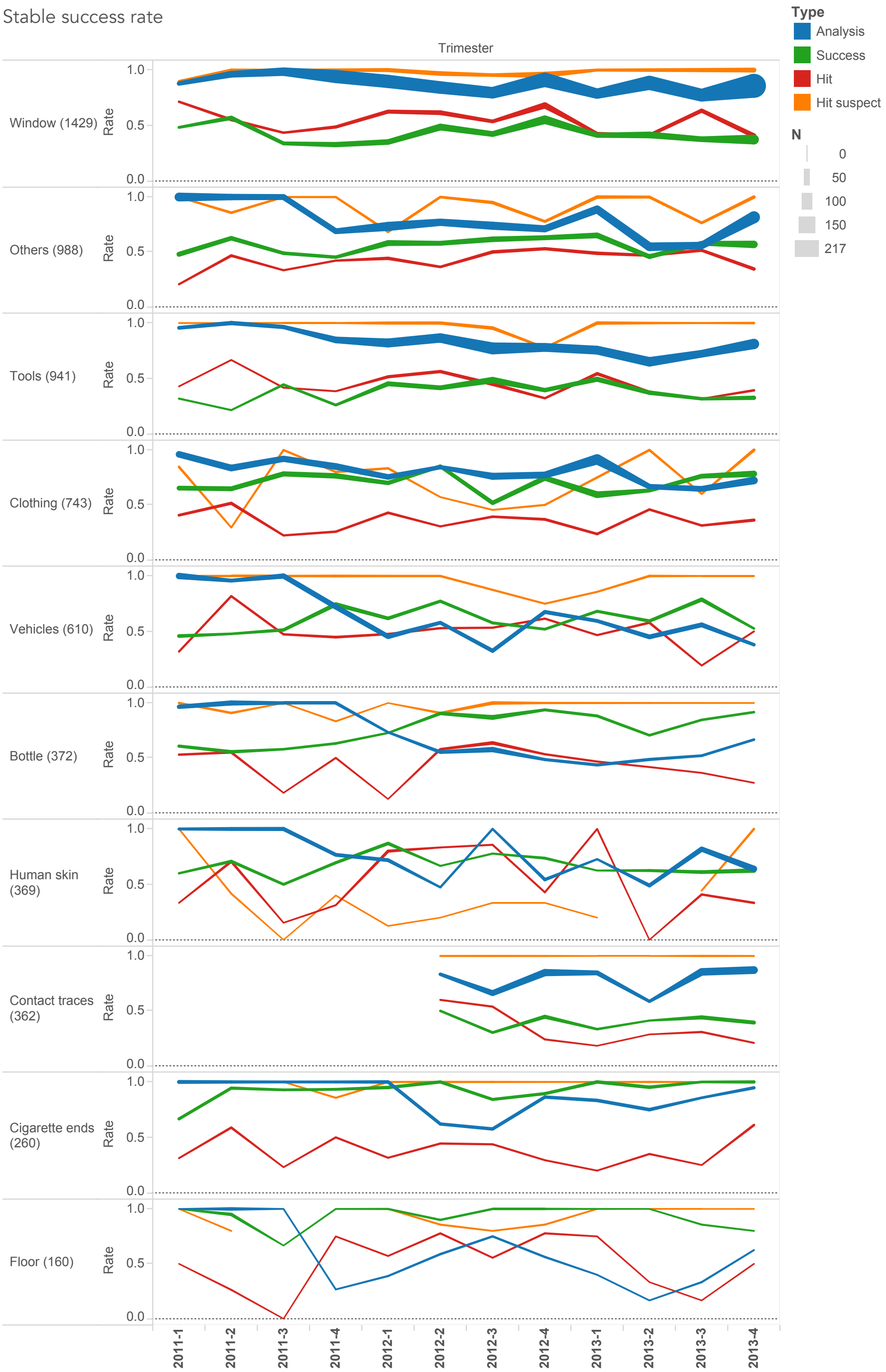

Fig. 6.19.: Analysis rate, success rate and hit rate and hit (suspect) rate over time for 10 matrices, having stable success rates over time. The size of the lines represent the sample size, for the analysis rate it is the number of analysed traces, for the success rate, it is the number of positive results, for the hit rate, the number of hits, and for the hit suspect rates, the number of suspect hits. Ordered by decreasing number of collected traces per matrix (in brackets).

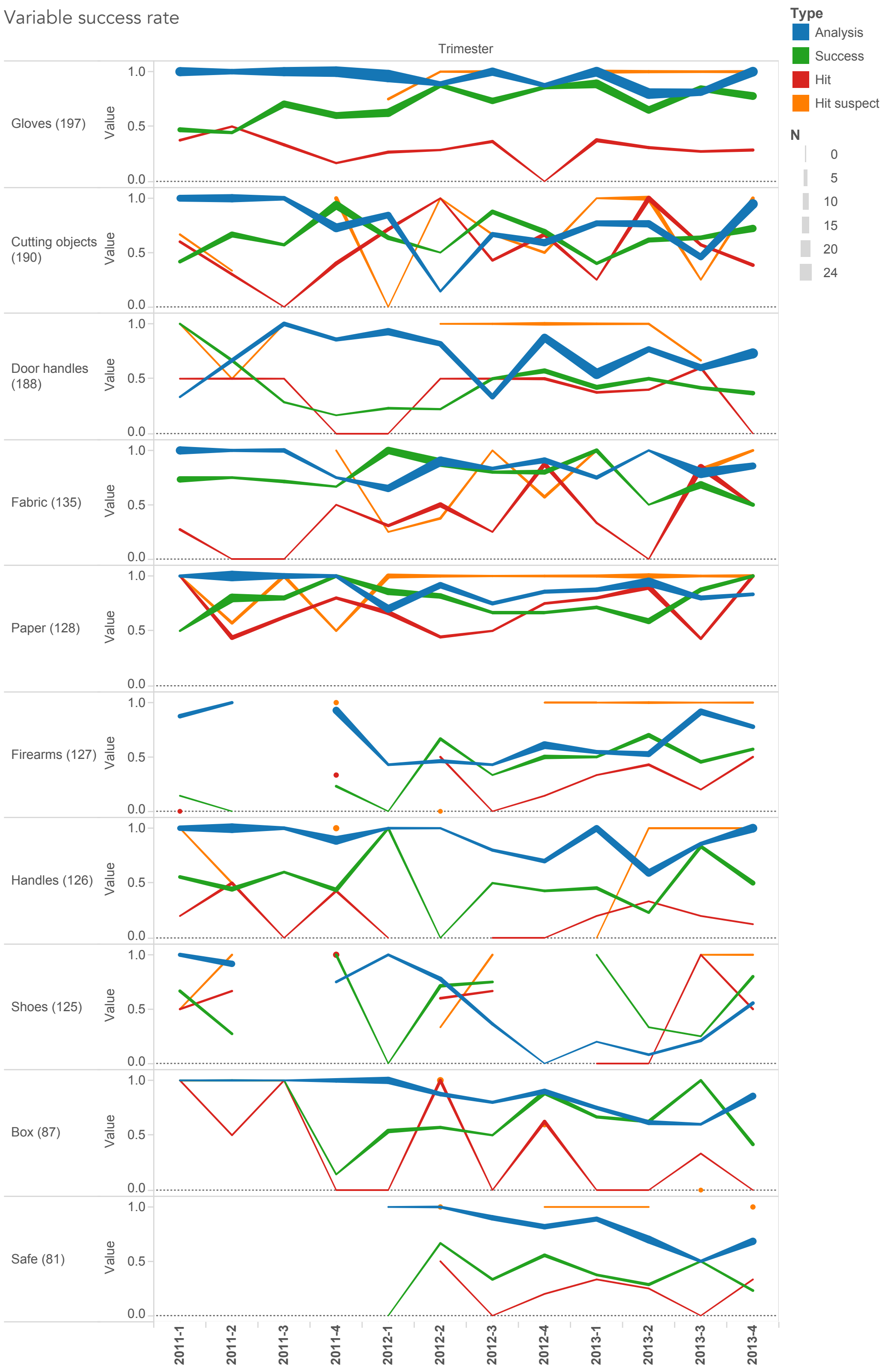

Fig. 6.20.: Analysis rate, success rate and hit rate and hit (suspect) rate over time for 10 matrices with higher number of collected traces, having variable success rates over time. The size of the lines represent the sample size, for the analysis rate it is the number of analysed traces, for the success rate, it is the number of positive results, for the hit rate, the number of hits, and for the hit suspect rates, the number of suspect hits. Ordered by decreasing number of collected traces per matrix (in brackets).

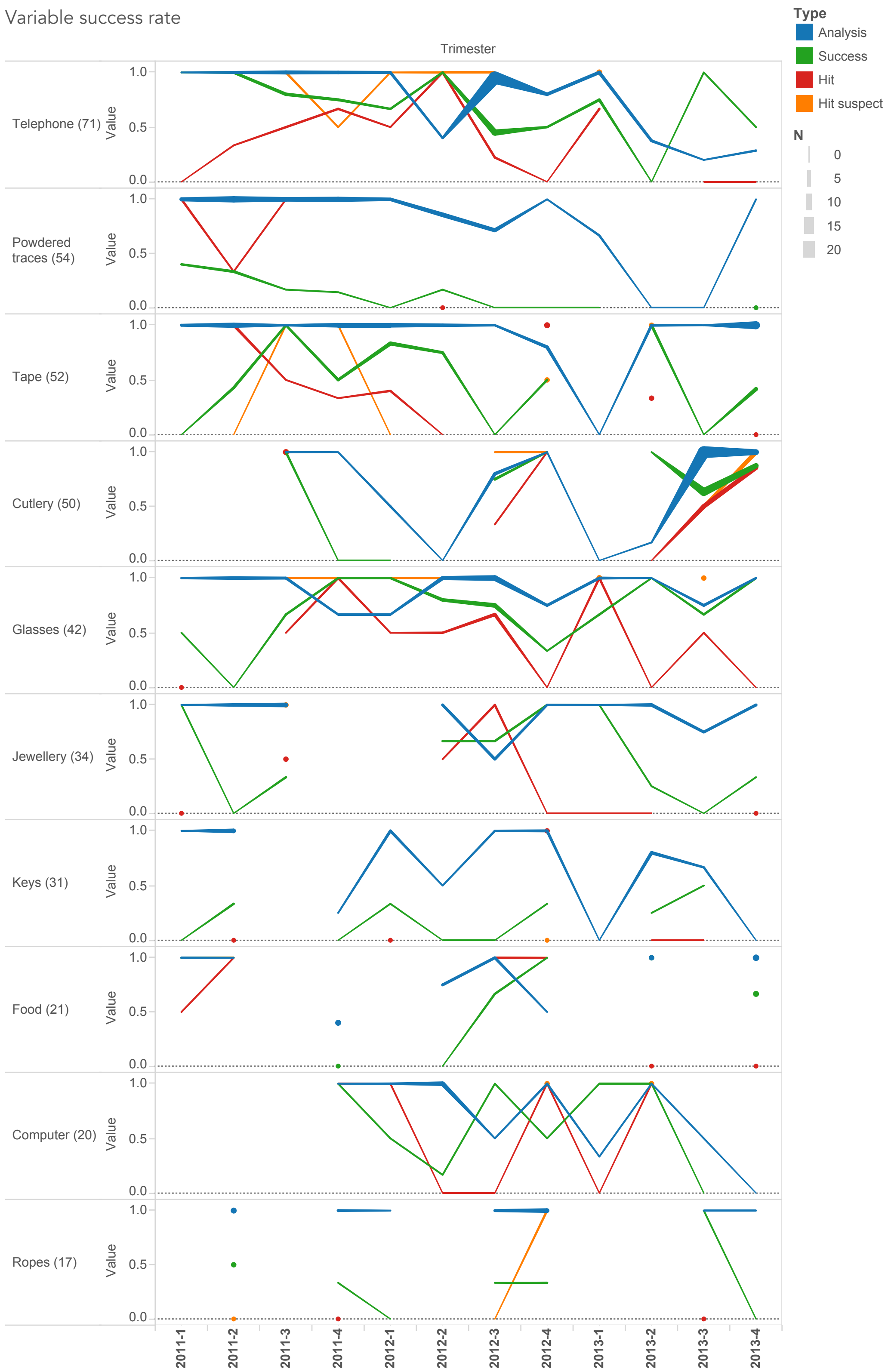

Fig. 6.21.: Analysis rate, success rate and hit rate and hit (suspect) rate over time for 10 matrices (with small number of collected traces), having variable success rates over time. The size of the lines represent the sample size, for the analysis rate it is the number of analysed traces, for the success rate, it is the number of positive results, for the hit rate, the number of hits, and for the hit suspect rates, the number of suspect hits. Ordered by decreasing number of collected traces per matrix (in brackets).

Tab. 6.7.: Comparison of the success and hit rates of some of the featured matrices with the values shown in Baechler (2016) and Mapes et al. (2016). (*): Success rates for Baechler (2016) and Mapes et al. (2016) consider single profile results (sum of single and mixed profile results in brackets). The values marked with (**) are averaged values of the categories: 'Hand-tools','Screwdriver','Knife grip'. (***): 'Headwear', 'Ballcap', 'Sleeve cuff' and 'Fabric glove'.

Matrix	Success rate* (%)			Hit rate (%)		
	Baechler (2016)	Mapes et al. (2016)	Current study	Baechler (2016)	Mapes et al. (2016)	Current study
Cigarette ends	70.6	84 (87)	91.7	35.3	57	38
Tools + Cutting objects	10.7	11.7 (16.3)**	43.3	20.2	50**	45.9
Bottle + Food	55.6	-	73.4	22.2	-	48.2
Shoes	-	21 (38)	53.2	-	50	60
Glasses	-	19 (19)	65.8	-	17	52
Tape	-	9 (9)	52	-	75	38.5
Keys	-	12 (14)	26.1	-	50	16.7
Clothes + Gloves	18.8	32.8 (64.8)***	69.1	40.6	50.3***	33.3

always pertinent, i.e. if it was the information one was looking for. As previously mentioned, this category is particularly obscure (as well as the category 'Others'), as a range of different matrices can fall into that classification. Notably, this code was introduced in the second trimester of 2012.

'Door handles' started off with a very high success rate and average hit rate. Then, the analysis rates rose, and the success and hit rates dropped. Traces originating from the matrix category 'Window' are constantly analysed, albeit the success rates, as well as the hit rates, lie stable below or around 0.5. When a hit is yielded, it is in nearly all the cases a suspect hit. Assuming that for this type of matrix, the suspect hit is pertinent, the choice for this trace on this matrix is justifiable although the success rates are low. Traces collected from 'Tools' are decreasingly analysed, and the success and hit rates are low. However, similarly to 'Window', the yielded hits are very often suspect hits.

In previous studies, statistics regarding the success and hit rates depending on different matrices were determined. Baechler (2016) focussed on the Swiss canton Neuchâtel, with a sample size of 4772 biological traces, collected from April 2012 to October 2014. Mapes et al. (2016) studied the success and hit rates of biological trace analysis in the Netherlands, 2260 collected biological traces were included in their study, in the study period from January 2012 to December 2013. When comparing these results to the ones presented by Baechler (2016) and Mapes et al. (2016), the values of success and hit rates for only some matrices can be compared, as only a few of the matrix codes are the same (see Table 6.7). It can be noted, that most of the values, for success and hit rate, are very variable among the different studies. For 'cigarette ends', for instance, the overall success rates range from 70.6 to 91.7%. Similarly, the hit rates in the two Swiss studies are at 35.3 and 38%, whereas the Dutch study yields a hit rate of 57%. 'Tape', having a low number of collected traces, is one of the matrices that showcase a very variable success rate (see Figure 6.21), and when comparing to the data produced by Mapes et al. (2016), one can see a big difference (9 versus 52%). The hit rates for this matrix are reversed (75 versus 38.5%). Again, according to our data, these values are very variable over a period of time (Figure 6.21).

Some of these differences may be explained by a small number of collected traces and, thus, a small number of samples in the data. In addition, a difference in codification probably is at the source of theses big differences in values for success and hit rates for these categories of matrices. Another difference between the other two studies and the current study, is that their success categories are separated into single, mixed, complex and no result, whereas in our data, we only have the information of positive or negative result. For Mapes et al. (2016), the single and mixed profile results were aggregated to compare to the positive results in the present study.

As previously discussed, the simple limitation to the success rate is insufficient when considering the contribution of the clues. However, the question of the hit and hit (suspect) rate is also complex. It depends on the information one wants to retrieve from the object (for instance, for 'Clothing': is the carrier of interest or somebody who had an external contact with the carrier of the clothing), the collection technique and the implication of the object in the case. As previously noted, not in every case, the suspect's profile is of interest. The trace can stem from the suspect's clothing (suspect might have been identified through police inquiry), and the victim's profile on his clothing would link both persons. In this case, finding the suspect's profile on his clothing is not the challenge. In the scope of this study, it was however not possible to account for all these nuances.

In general, the extraction of information from the descriptive statistics of Figures 6.19–6.21 is delicate and requires a sufficient amount of circumstantial data, especially if this data should guide the prioritisation of the traces (as suggested by Mapes et al. (2016)).

Similarly, the variable considering the number of offenders is not retained in the decision tree model. One would hypothesise that the higher the number of offenders the more traces would be analysed per case, and thus the higher the likelihood of analysis of the trace. However, this does not reflect the actual situation.

The decision to analyse a trace first The model created with the dataset considering the first batch of traces analysed as dependent variables is more complex than the previous one (see Figure 6.22).[15] The very first decision regarding the analysis of biological traces, i.e. the decision for the first batch of analysis, does not seem to be straightforward; 15 out of the 23 available variables were used to construct the model. Again, factors related to individuals (for instance membership to a certain team of crime scene investigators) are affecting the decision to analyse a trace, as well as the knowledge about identification in the case, this time through a different type of forensic trace, and the police inquiry progress. In addition to the important factors highlighted in the previous model, the number of offenders, the type of robbery (armed robbery), the matrix of the trace, the number of collected fingermarks and shoe marks, and the targeted location (i.e. service) affected the decision regarding the first batch of analysis.

The variable in the first node is the presence of an identification through other traces in the case. This information can be available through fingermarks but also through a shoe mark comparison after the suspect has been identified through police inquiry. The decision to analyse a biological trace thus depends on the results delivered by other types of traces, often considered of lesser importance.

When no identification has been obtained and only one biological trace was collected in the case (node 3), almost all of them are analysed. This result is not surprising, as it is the sole biological trace they have in the case, and thus no triaging needs to be done.

The decision to analyse a trace first is only applicable in cases with multiple collected traces. However, in the scope of the article, the model was applied to the complete

[15] see detailed images in Appendix D in Figures D.2 and D.3.

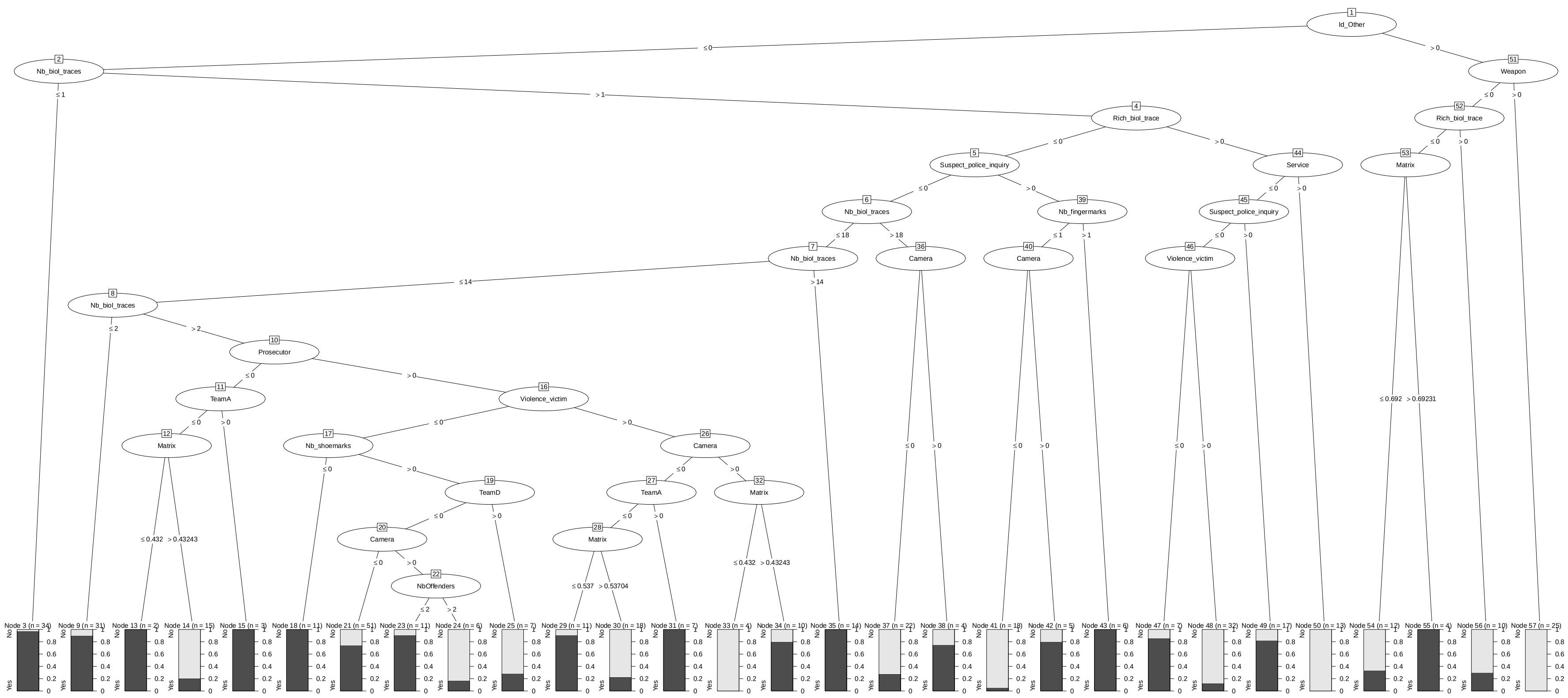

Fig. 6.22.: C5.0 decision tree model of the first batch analysis. Enlarged images of this model can be found in Appendix D in Figures D.2 and D.3.

dataset (N = 410). The model, generated when using solely the traces that have been collected in cases with multiple collected traces (N = 374), is shown in Appendix D in Figure D.4. The difference between the two models is that the variable *Nb_biol_traces* is removed, the subtrees remain the same. Hence, the discussion of the results is not modified.

In armed robberies (node 51, with an identification available through other traces), no biological traces were analysed. This result seems counterintuitive, as the case is considered more serious when a weapon is used. However, this finding is the reflection of the situation: it can be explained due to the circumstances of this kind of cases. When a weapon is used, more often than not, there is no contact between the offender and the victim/scene. Hence, fewer traces are considered useful to the case, and thus submitted for analysis.

However, some of the variables have different influences depending on the subsample. When comparing nodes 12 and 32, and their outcomes in nodes 13 and 14, respectively 33 and 34, it is noteworthy that the proportion of analysed biological traces is influenced in both directions by the same variable (the matrix of the trace) and a similar split criterion. The logical way would be to choose a higher number of traces for the analysis when the matrix is propitious for yielding a positive result. However, the decision to analyse a trace does not seem to always follow this logic (see also Table 2, a higher proportion of traces on less propitious matrices are analysed compared to the analysis rate of traces on propitious matrices), although this is one of the guidelines in this forensic unit.

The factor *Matrix* can be very variable for certain matrices over time, especially for matrices with small numbers of collected traces (see Figure 6.18). In this model, the factor corresponds to the average of the success rates for the previous 4 trimesters per matrix and thus, the variation can be lost. Due to the big differences between consecutive trimesters, it can occur, for instance, that the average is slightly above 0.5 (propitious matrix) although 3 out of 4 values were below, which would rather indicate a non-propitious matrix. These variations are thus difficult to see and might influence the decision-making process when choosing which trace to analyse first.

In this model, information about a known crime link was not considered to be important for the decision to analyse a first trace. It must however be considered that this variable is probably incomplete, in the sense that some observations were coded as 0, although a crime link was known, and thus, should have been coded as 1. However, this information was not available in the database. It has been however observed during the participant observation, that a series of cases with similar modus operandi is occasionally emphasised at daily meetings, but this information is not registered in the database, and can thus not be traced back.

Sequence of analysis The decision to analyse a trace first emphasises also the question regarding the sequence of analyses when multiple traces were collected. Two situations can be distinguished: (1) the case when multiple traces of the same type are collected and analysed in different batches and (2) the case when different types of traces were collected.

Same type of traces In cases with multiple collected biological traces, their submission for analysis can be done in multiple batches (the data shows that it ranges from 1 to 3 batches). Two opposing hypotheses could be set up: either the first chosen traces are the right traces in regards to their success rate or even their hit rate or the crime scene investigators are right to choose further traces for analysis and the collected traces are all potentially useful.

According to the results shown in Figure 6.23, the success rate for obtaining a positive result decreases from the first batch to the third batch of analysis. Whereas, the hit rate decreases slightly in the second batch, but increases at the third batch. This result would indicate that the first traces that are sent to laboratory for analysis are chosen based on the statistics of success rate of the typology of traces, instead of their hit rate. Similarly, the last traces (batch 3) contribute in majority to the number of pertinent identifications. This result needs however to be considered with caution. The hit rate is influenced by the fact that the same offender might be identified a second time within the same case. In addition, the second and third analysis batches are performed later in the case, thus more time has passed, hence, if a suspect has been identified between two analysis batches (and thus has in the meanwhile been added to the database), a hit is much more likely.

Taking into account these nuances, an additional notion – new pertinent hit – is introduced. In this case, the hit does not only need to be pertinent, thus link the

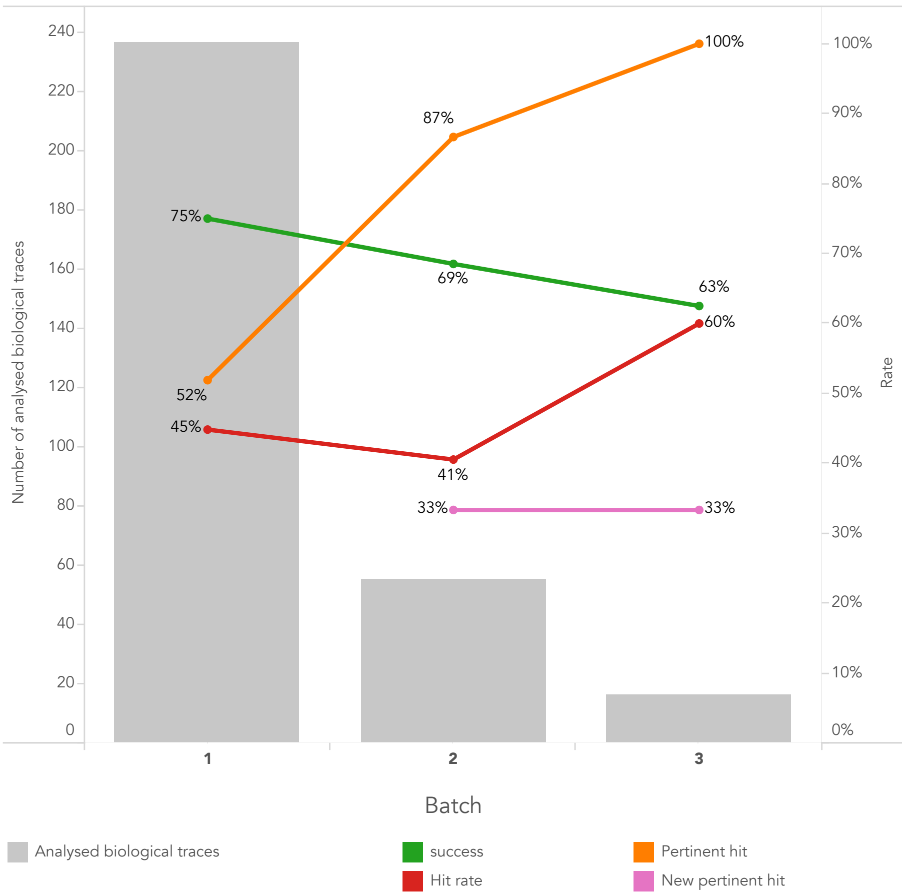

Fig. 6.23.: Number of analysed biological traces per batch of analysis (bars). Success rate (green) of obtaining a positive result decreases with increasing batch number, whereas, hit rate (red) and the pertinent hit rate (orange) increase, and the new pertinent hit rate remains stable (pink) between the second and third batch. The new pertinent hit rate corresponds to the number of hits generating a new name at the second or third batch compared to the total number of hits.

suspect to the case or to the victim or link the victim to the suspect, but this pertinent hit also needs to be new. A confirmation of the same hit obtained through the analysis in a previous batch is not considered in this case. The rate is calculated by the number of new hits relative to the overall number of hits. The values remain stable between batch 2 and 3: the same percentage of new suspects (33% of number of number of hits) were identified in batches 2 and 3.

The sample size being extremely limited, the values are very small and thus only a trend can be observed, without being necessarily generalisable. In addition, the possibility of a hit depends on whether the person is registered in the database.

Similar results were obtained in a small study performed by the head of the forensic unit of the canton Valais (Pitteloud, 2014). For two linked burglary cases, after the arrest of the suspects, the prosecutor's office demanded the analysis of all remaining non analysed biological traces in the cases. This opportunity allowed to assess the performance of the triage performed by the forensic unit. The triaging criteria in place are the type of offence, the seriousness, the loot, the links between cases, the quality of the trace, the type of matrix and the supposed intensity of contact. The results of the triaging by the forensic unit were good considering the percentage of useable profiles obtained after analysis (77% for traces analysed at the initiative of the police, compared to 40% at request of the public prosecutor). The hit rates (number of hits to positive results) were very different (40 compared to 88%). Again, one needs to consider the fact that the suspects were already arrested at the moment of the analyses ordered by the public prosecutor. Indeed, only one new suspect was revealed through these hits, while the others were repetitions of previously known identities.

Different types of traces One hypothesis was that the presence, analysis and/or result of analysis of one trace would influence the analysis of another trace. That's why, the sequence of analysis of the different traces, considering the different types of traces, is studied.

In the general model (Figure 6.13), the analysis of shoe marks or fingermarks was not considered important for the decision to analyse a biological trace. In 34 cases, shoe marks and fingermarks were analysed, with 61 analysed shoe marks of 65 collected ones. In 13 cases, shoe mark analysis was carried out before biological trace analysis, in 6 cases it was at the same date, and in 15 cases the biological trace analysis preceded the shoe mark analysis. Out of these 15 cases, in 13 cases, the shoe mark analysis was performed prior to obtaining the result of the biological trace analysis. The shoe marks enabled us to link a suspect to the scene in 5 cases. In all of these cases, the suspect had been identified previous to the analysis by police enquiry.

In 6 cases, fingermarks and biological traces were analysed. In 5 cases, the analysis of the biological trace(s) preceded the analysis of the fingermark(s), however, in 4 cases, the fingermarks were analysed before the result of the biological trace analysis was obtained. In 1 case, the fingermark analysis was performed prior to the biological trace analysis, and a hit was obtained prior to biological trace analysis, too. In all cases with fingermarks, 9 hits were generated, pointing always to the suspect's identity (4 cases). In 2 cases, this information was the first information regarding the identity of the suspect, and in 2 cases the suspect's identity was confirmed after it was determined through police enquiry.

The analysis of fingermarks is performed after biological trace analysis submission (but before retrieval of results), a preference can be observed for biological traces. However, crime scene investigators don't seem to just put 100% of trust in those, but also put their chances on other types of traces.

Case example *The following case example (in Italic) is reproduced verbatim from Bitzer, S., Albertini, N., Lock E., Ribaux, O, and Delémont, O. (2015). Utility of the Clue – From assessing the investigative contribution of forensic science to supporting the decision to use traces. Science & Justice, 55(6):509–513.*

> *An example is given to showcase the utility of the clues in the case, and their changing nature depending on the available information. It mimics, in a simplified manner, a combination of situations of real cases.*
>
> *Let's consider a robbery case (one offender seen on surveillance camera images) with one shoe mark and two biological traces collected at the crime scene. The general expected utility of the shoe mark is to link cases with each other. One biological trace is analysed to identify the offender The decision for one of the two biological traces was made on the basis of the quality of the trace, the matrix, the pertinence of the trace, etc. The analysis of the general pattern of the shoe*

mark permits, already at the crime scene, to give information to the enquiry in terms of shoe brand. The course of the offender does not need to be reconstructed by the shoe marks, as the surveillance camera images are available and already provide a detailed sequence of the offender's actions. This sequence of actions can help choose pertinent traces, which can generally be considered a form of utility of the shoe marks. The result of the analysis of the biological trace is positive and a profile is yielded (different from that of the victim). However, no DNA match could be provided when comparing with the National DNA database. Hence, the utility a posteriori is null, except for its exclusion potential. The expected utility of the not analysed biological trace is low, as the profile already available can reasonably be attributed to the offender due to the high pertinence of the trace. If the pertinence would not be given, it could still be reasonable to wait until the result of the first analysis is obtained before analysing a second trace (to prevent redundancy).

In a second robbery case, the offender is arrested immediately after the offence, due to police investigation. In the audition, the offender denies any implication in other cases. At the second crime scene, one shoe mark and one biological trace are collected. The analysis and comparison of the shoe mark reveal a possible link with the first robbery case. The biological trace is not analysed. However, a buccal swab of the offender is performed and analysed. A DNA match with the biological trace from the first robbery case is yielded. Confronted with this result during audition, the offender confesses to having committed the first robbery, too. The utility a posteriori of this biological trace changes then to aid in the inquiry/audition and confirmation of the implication of the offender in the case. The not analysed biological trace from the second robbery has an expected utility of confirmation of the implication of the offender (validation of the confession and corroboration of the possible link unveiled by the shoe marks).

6.3.3 Discussion

The applied methodology, combining both quantitative and qualitative approaches enabled to focus on the decision-making process related to the decision to analyse a trace and to decipher the factors affecting it. In this study, the focus was on robbery cases, a type of offence, for which the crime scene investigation is supposed not to be too impacted by actuarial or managerial policy. Robbery cases were chosen as a compromise between high volume crimes, such as burglary, and serious cases, such as homicide cases. In high volume crimes, the triaging step occurs already at a previous step, when collecting the traces. This probably stems from the anticipation of the decision to analyse a trace, and the application of the corresponding guideline, to the collection step. Once a trace is collected, it is analysed, thus, the decision to analyse a trace is not considered in these cases. In homicide cases, on the other hand, many resources are invested during the collection phase, and a more selective triaging step occurs previous to the analysis of traces. However, the dataset for these cases is too limited. Robbery cases can be considered a hybrid form in regards to trace processing between the previously described cases. As they are very diverse, from the street robbery of a handbag to the armed robbery of a jewellery store, some cases are handled more like burglary cases, whereas others are processed like homicide cases.

> A decision tree model was chosen to follow the decision paths to get an informed picture of the variables influencing this decision. When considering the decision tree and following the decision criteria through the tree, a variety of variables appear as important to the decision, for the general model but also, and especially, for the first batch of analysis. The results showed that all the suggested knowledge dimensions affect the decision to analyse a trace. Some, such as the criminal dimension, only act on a specific subsample within the decision tree. The utility dimension, referring to previous knowledge available in the case, is particularly important and interesting to note.

Generally, crime scene investigators recognise the identification potential of traces, and decide about the analysis of biological traces according to the knowledge of an identification of a suspect prior to the analysis of biological traces. The analysis rates change drastically depending on this variable. When a suspect has been identified, the seriousness of the case is of importance regarding the analysis of biological traces. When the victim was attacked, the analysis rate increases, whereas in the other case, when no violence was inflicted to the victim, the analysis rate dropped close to 0. In these cases, the reasons for performing the analysis nonetheless were the reconstruction or the determination of the legal qualification of the case.

The knowledge of a suspect identification might not only influence the number of traces to be analysed, but mostly which traces are analysed. This could not be investigated in detail for all of the cases. The influence of violence against a victim on the decision to analyse a trace, although a suspect had already been identified, shows that biological traces are used for multiple purposes, according to different utility dimensions. In addition, the identification utility of biological traces could be confirmed. Nonetheless, other traces, in particular fingermarks and shoe marks are also analysed; one mainly for identification, the other for crime linking purposes. Although the analysis of these types of traces is regularly performed after the submission for analysis of biological traces, the high analysis rates of these traces show their high perceived value.

We can hypothesis that the impact of the criminal dimension might be more important in different types of offences, with a more affirmed seriality, e.g. burglary cases.

> The results and the appreciation for the utility of the clues can be partly explained by the environment in which the analysed forensic unit is embedded: in this case, a decentralised police system with many contact points between scientific and police investigators, crime scene investigators who are more generalist than in other countries and thus more concerned about using police information and more sensitive to the question of utility.
>
> In both settings, the general model and the first batch analysis, the knowledge of a positive result or of an identification through other traces affected the decision to analyse a trace in a statistically significant way. These findings are contradictory to the findings in the literature that emphasise that the main reason repeatedly mentioned for the analysis of a trace is to build a case against a suspect, and similarly, the main reason for the non-submission for analysis of a trace is that no suspect has been found. In the specific context of our study, we observed that the crime scene investigators took into account the knowledge about suspect identification through police inquiry or other types of traces for their decisions to submit biological traces for analysis, submitting fewer traces for analysis when a suspect was known. This suggests that they emphasise the potential of biological traces, in relation to a reference database, to gather intelligence and do not solely see the confirmation utility of biological traces as evidence to be presented for court purposes. Moreover, it appears from a detailed study of the cases that the biological traces were not solely used for identification purposes but also for the reconstruction of the event or the determination of the implication of different offenders.

The use of biological traces not only for confirmation purposes might be promoted by a favourable context for DNA analysis in Switzerland, with analyses performed within several days.

One interesting finding relates to the nature of the trace itself. In both models, it appears that the matrix of the trace was not statistically significant in the decision to analyse the trace. Another factor relating to the trace itself is its type ("rich" vs contact trace), assessed by the results of presumptive tests. While this factor was statistically significant, its influence was negative, in the sense that a "rich" biological trace is less likely to be submitted for analysis. Despite this observation seeming inconsistent at a first glance considering the possibility of obtaining a full DNA profile, it makes greater sense when taking into account the situation and the expected utility of the information conveyed by the trace. This is highly interesting from our perspective as both factors – the matrix of the trace and its "quality" – are commonly used in guidelines or policy documents to support the decision to proceed to a DNA investigation. While these factors may indeed favour the chance to get an analytical result of good quality (DNA profile), they are not good predictors (on the contrary) of the utility of the information conveyed by the trace for the inquiry. In this sense, managerial policy, funded on apparent efficiency and taking into account only a narrow aspect of the multi-dimensional contribution of forensic science to the criminal investigation, while very popular and seemingly efficient, may have negative consequences.

Contrarily to the guidelines in place in some of the investigated forensic units, the matrix of the trace and the related success rates are not reliable criteria for deciding which traces to analyse. When considering the success rates of 30 different matrices over the course of 3 years, only 10 matrices can be considered stable. At the same time, this means that 20 out of 30 matrices yield variable success rates. That is why, crime scene investigators can not make a right choice solely based on the matrix of the biological trace.

Another approach can be adopted by looking also at the hit rates for those matrices. Some patterns can be found. Some matrices are prone to yielding a stable high success rate, however, only a very low hit rate or hit (suspect) rate. Whereas, others, yield only a few times a positive result, however when they do, a hit is obtained.

Financial aspects, considered through the variable *Prosecutor*, appear to play only a limited role in the decision to analyse a trace, contrarily to the common belief that the decision is mostly economically driven. When the prosecutor is in charge of the case, he is also responsible for the financial side of the investigation, and hence the analyses of the traces. In the decision tree model

> of the general dataset, this variable appears only at the bottom, and hence only in very specific cases. Hence, efficiency is not considered a key variable in the decision-making process.

The influence of the economical aspect is often mentioned for crimes that are considered less important (volume crimes).

> The decision to analyse (or not) a trace appears to be very complex, context dependent, limited by the situation and case-specific. Consequently, it seems very difficult, and scarcely relevant to establish rigid (managerial) guidelines for this decision step. On the basis of the results of our study, it appears that some variables are important under very specific circumstances, in subsamples in the trees. While it is of foremost importance to highlight that the explicative models and the results presented in this manuscript are highly dependent on the police structure where the study took place, and that they may not be valid in other environments, they however suggest that the different decision steps encompassed in the overall process of forensic science's contribution in the criminal investigation should be the subject of more scrutiny.

The participant observation proved to be difficult as the crime scene investigation of many cases was missed. Several constraints led to this, such as the time of the event, the crime scene investigators were initially not informed to include the author in the investigation. Hence, only a limited number of observations could be made allowing only descriptions of distinct situations and all attempts of generalisation are in vain. Furthermore, a generalisation of the conclusions to other types of crimes is very delicate.

7

Utility and the performance of forensic science

The implementation of utility of the clue as performance indicator can also be seen as the utility *a posteriori* of the used traces, once the analyses have been performed, their results are known, context information has been clearly determined (e.g. number of suspects), etc. Different utility dimensions of the clues in the cases under scrutiny will be presented. Another aspect of performance measurement is the consideration of the expected utility (projection) of the clues, in comparison with the utility *a posteriori*. In like manner, the expected utility of the non-used traces, without knowledge of their analysis outcome, can be evaluated.

7.1 Trace attrition: *a posteriori*

A posteriori, the analysis rate in STI cases lies at 85% (N = 143), with the number of traces that have not been analysed although no information is available regarding the identity of the offender summing up to 22 (143-121) traces (see Figure 7.1). For 16 unanalysed traces, no information at all is available regarding the identity of the offender (see details about the not analysed traces in the section below). Only 20% of traces with positive result yield a hit and 44% of these hits can be considered pertinent. This means that 7 traces yielded a pertinent hit but there is still information to gain about the identity of other offender(s). In three out of these 7 cases, no information at all is available, as the individual identified by DNA trace could be excluded through police enquiry. In the other cases, a hit led to the first suspect, but a second (or more) suspect(s) remain(s) unidentified.

In SI cases (N = 267), 68% of traces have been analysed. The majority of cases has been solved through police enquiry, nevertheless, the majority of traces has been analysed for these cases. For 30 traces, a pertinent hit was yielded in cases with a suspect identified through police enquiry. When subtracting the 8 traces which were analysed prior to case resolution through police enquiry, 22 traces remain, for which a pertinent hit was obtained. These 22 traces had an expected utility of identification, however, the posterior utility is different, as the identification was provided by the police enquiry. In these cases, the hits thus allowed to confirm the suspect's identification. In all cases, objects related to the activities (cutting objects, firearms, ..) were analysed. The interpretation of these hits also allowed to reconstruct the events.

7.2 Utility dimensions: *a posteriori*

In this section, different utility dimensions in the studied cases will be considered in a retrospective manner. The dimensions of *identification*, *confirmation / reconstruction*, *linking cases*, and *other dimensions of utility* will be highlighted here.

7.2.1 Identification

A posteriori, 51 cases still had STI (see Figure 6.7): in 45 of these cases, no information was available, in 2 cases a suspect could be identified through police enquiry and, in 4 cases, a suspect could be identified through trace analysis. In 50 cases, the suspect(s) had been identified (SI): in 36 cases, this happened through police enquiry, in 12 cases the identification was yielded through trace analysis and in 2 cases, the offender turned himself in.

In total, the contribution of trace analyses and results (both biological traces and fingermarks) to suspect identification could be shown in 16 cases (4 (STI) + 12 (SI)). In 16% of robbery cases in 2012–2013, the first information regarding the identity of the alleged offender was yielded by the results of trace analysis. When subtracting the cases that were solved *a priori*, forensic science contributed to the identification in 16 out of 86 cases (19%). This value is substantially higher than the value determined by Brodeur (2005), who determined that, in homicide cases (committed between 1990 and 2001), the contribution of forensic science to suspect identification was amounted to 2% of cases. In addition to the different study period influencing the use of forensic science, a factor contributing to this low number is the quick resolution time through police enquiry, which is a consequence of the characteristics of homicide cases (often involving offenders known to the victim). Thus, trace analysis is simply not 'necessary' anymore to identify the suspect,

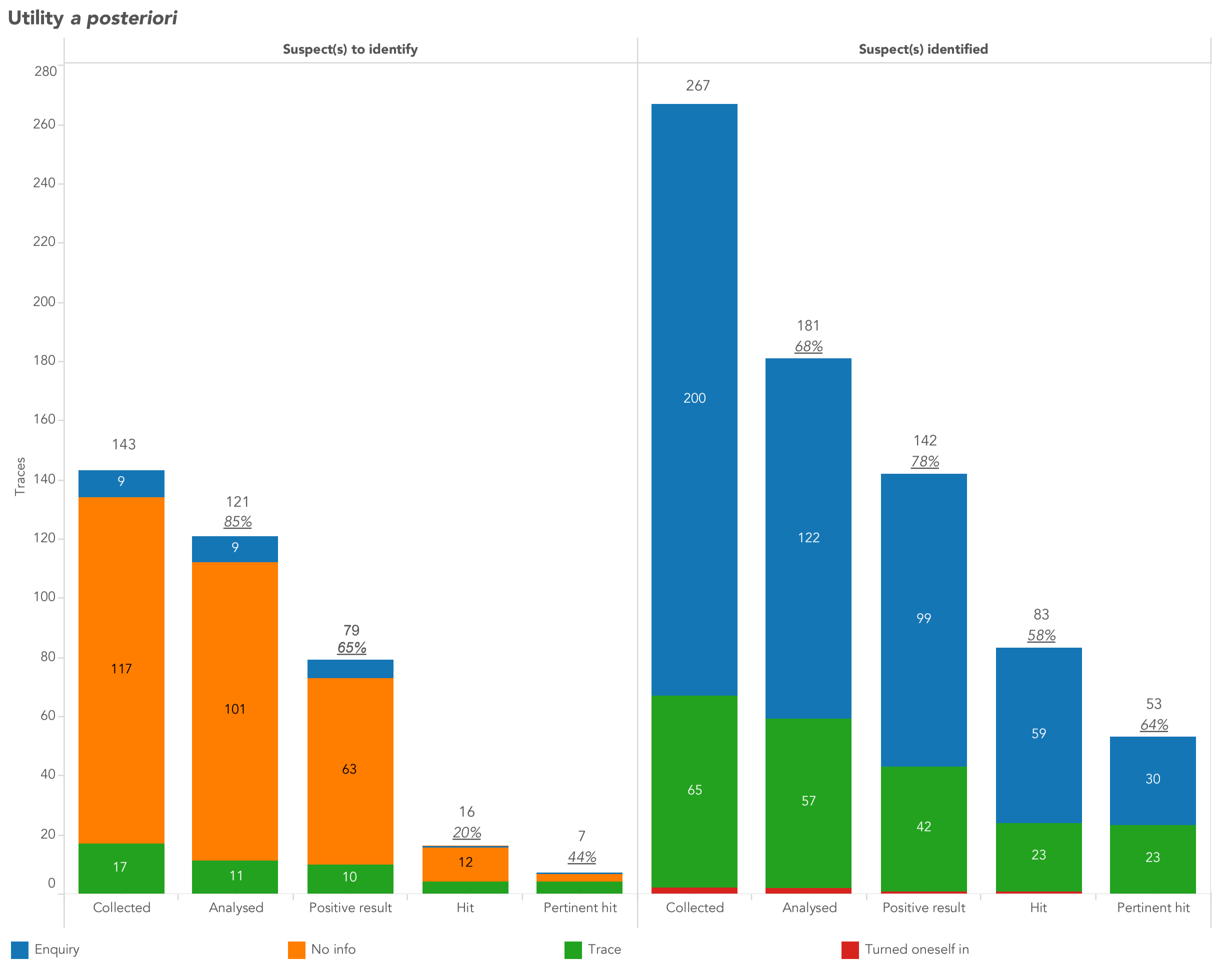

Fig. 7.1.: Trace attrition considering the utility *a posteriori*: no suspect identification or suspect identification, considering the resolution of the case. From the number of collected biological traces, analysed, those yielding a positive result, those generating a hit, and those generating a pertinent hit. In italic the analysis, success and hit and pertinent hit rates.

eliminating the utility *a posteriori* of identification in a high number of cases. In this study, focussing on robbery cases, this attribute of relatedness between the victim and the offender is not present. Forensic science has a higher chance of contributing to the identification of the suspect in these cases, which could explain the difference between the two results.

The difficulty to compare these different types of cases highlights the importance to consider the SI and STI cases, *a priori* and *a posteriori*, when evaluating the contribution of forensic science to the identification of the suspect(s) in the case.

7.2.2 Confirmation / Reconstruction

When considering solely the identification purpose, the utility of the clue can be questioned when, in the end, an identification was reached through multiple sources, such as police enquiry and trace analysis, and thus, the contribution of the inquiry is considered more important.

In 13 cases, pertinent hits were yielded, but the suspect has been identified through police enquiry. In all of these cases, and based on the available information about the case, the contribution of biological traces to the investigation can be attributed to confirmation or reconstruction of events.

Out of these 13 cases, in 8 cases the suspect identification was reached after the analysis of the trace, i.e. during the analysis time, between the submission to analysis and the provision of the results. In 6 out of 8 of these cases, where the trace analysis result confirmed the alleged offender's identity, a confession was reached. In 4 out of these 6 cases with confession and with analysis prior to this confession, in addition to confirming the suspect's identity, the suspect turned to the confession right after the result of the analysis was presented to him. The sample size being far too limited, no statistical relationship is presumed here. Nonetheless, the result seems interesting and provides information about the complete range of utility dimensions of forensic science in the investigation.

Overall, in 29 cases, suspects confessed to the alleged crimes. This means that out of the 56 cases with a suspect (50 SI + 2 STI Enquiry + 4 STI Trace), in 52% cases, confessions were made. In 12 out of these 29 cases, a pertinent hit through trace analysis had been yielded (41%).

In addition, it needs to be noted here that in all of these cases, the *a priori* utility of the clues could be attributed to identification, as the analysis was performed prior to the identification of the suspect by the police. In one case, an identification of a first suspect had been reached prior to analysis, however, a second suspect was identified subsequent to the analysis of the trace. For identification purposes, it was indeed legitimate to analyse traces in these cases.

This shows the difference of the expected utility at the moment of decision-making and the actual utility, evaluated after the analysis. The evaluation of the one to the other allows us to study in detail the importance of this decision-making step (see section 7.3).

In 13 cases, fingermarks were collected, whereas in 11 cases these were analysed. In 4 cases, hits were reached through fingermark analysis and comparison to the database. As described previously, in 2 of these cases, the suspect information was the first information. In the other 2 cases, the match confirmed the suspect identification found through police inquiry.

7.2.3 Linking cases

Another advantage for choosing this type of offence is that robbery cases are known to be serial in nature, or at least to a certain percentage (Rossy et al., 2013). Thus, the *criminal* dimension could potentially play a role and it would be possible to study its influence.

In the study regarding the decision to analyse a trace, the knowledge of the crime link is of importance. The links considered in this study are either within the cases under scrutiny or with other cases. As solely the knowledge of such a link can potentially influence the analysis strategy. During the participant observation phase, a discussion between a police investigator and a crime scene investigator could be followed, about a series of cases that were known to be linked, and the remaining traces potentially useful to the case. They discussed the remaining possibilities and the analysis strategy to put in place.

This link is known prior to analysis (prior to batch 1, or in between batch 1 and 2, etc.) in 7 cases (see details in Table 7.1).

Tab. 7.1.: Number and types of cases linked *a priori* and *a posteriori*. (*) before or in-between two batches of analysis.

	Linked cases	
Type of link	**A priori***	**A posteriori**
Location	3	9
Modus Operandi	-	2
Involved person	1	2
Biological traces	2	18
Fingermarks	-	2
Shoe marks	-	1
Recidivist	1	25
Total	*7*	*59*

Tab. 7.2.: Number of recidivists considering crimes committed previously.

Type of previous case	Number of occurrences
Robbery	49
Burglary / Theft	20
Offences against property	3
Other	7
Unknown	31

However, the information about crime links can help the police enquiry as well as the enquiry of the subsequent cases added to this series. In addition, this information can also feed other channels, such as the understanding of the general criminal situation. In this case, we consider the number of cases linked *a posteriori*, which in this case sums up to 59 cases. In the solved cases, where a suspect has been identified, in 25 cases the suspect committed another offence (previous or subsequent to the case in question).

In these 59 cases, a total of 110 offenders performed these cases. The type of committed offence by the recidivists can be found in Table 7.2. A little less than half of the offenders committed the same crime, i.e. robbery, whereas the other half diversified, i.e. committed a different offence.

Forensic science contributed to case linking in 21 cases. Compared to the 16 cases which contributed to finding the suspect (see section 7.2.1), 5 additional cases demonstrated a crime linking utility. One through a shoe mark comparison, and 4 additional links through biological traces. In these four cases, the suspect was determined through police enquiry or his implication could be excluded although a match was obtained through the biological trace analysis.

7.2.4 Other dimensions of utility

In addition to these obvious utility dimensions, there are several indirect, and thus difficult to study, dimensions. These could be observed during the participant observation phase at the forensic unit of the canton Vaud and a detailed case study of past cases.

An example are shoe marks which can also lead to other traces, by indicating the path that was taken by one suspect (following one shoe pattern), their interpretation might thus potentially point to locations for further, potentially invisible, traces, i.e. reveal contact points (role as catalyst of traces). Shoe marks, or better their quick analysis on the crime scene, might also feed the police offender profile, and thus direct their investigations.

As previously showcased in the case example, traces can help determine the legal qualification of the case.

In another case, a confession was yielded after the police investigator told the suspect that his co-suspect was linked to the case through a match between his profile and that extracted from the trace collected on the crime scene (role as catalyst of information).

7.3 Expected utility

The expected utility, for analysed traces in comparison to their actual utility or for not-analysed traces in comparison to the state of information in the case, will be discussed in this section.

7.3.1 Of the analysed traces

The consideration of the expected utility *a priori* when deciding which traces to analyse in a case could guide the prioritisation of the traces for analysis and thus be a valuable tool to justify the analysis strategy put in place. The consideration of the expected utility demands to question the relevance of the trace with the case, its pertinence to the user (Hazard, 2014) and its contextualisation with the available information in the case. This includes cognitive aspects such as knowledge of the crime scene investigators of the information potential of the traces, an assessment of the relevance of the trace to the case, an estimation of the success and hit rates, and the consideration of the previously available information in the case. In addition, the assessment of the expected utility is dynamic in nature, and depends thus on the information obtained. The changing expected utility is showcased in the case example below, explaining one of two cases that could be followed from the start of the crime scene investigation and involving the collection of multiple traces.

This application of the concept of utility can however only be studied in cases observed on the go, as it is nearly impossible to attribute the relative expected utility to traces in past cases. For instance, in some cases, multiple swabs were taken on the skin of the victim where the offender touched the victim, according to witness reports. In hindsight, it is impossible to set up a ranking of these similar traces.

The evaluation of the utility of the clues in the decision to analyse a trace at the moment of deciding which traces to analyse is a very ambitious objective and should be further developed. The determination that utility of the clue, thus all information available at the moment of decision-making, influences the decision-making process helps shaping the framework to study this question.

7.3.2 Of the not analysed traces

It can be hoped that all collected traces have a potential pertinence, or even a potential utility. In this case, the collection process would be considered effective. Concerning visible traces, such as shoe marks or fingermarks, most not analysed traces are considered of poor quality or as redundant subsequent to their collection and were thus not analysed. However, in regards to biological traces, a similar triaging strategy is undertaken, but postponed to the analysis step. It was noted during the participant observation stage that in some cases, only few traces are available (deduced from the case circumstances), which were not necessarily of good quality, nonetheless they were collected, although not compulsory submitted for analysis.

As biological traces were chosen to be submitted for analysis depending on whether

Tab. 7.3.: Reasons for not analysing remaining biological traces in case without any information regarding the suspect's identity. NA = Not analysed.

Case	Collected	NA	Reason	Explanation
1	7	2	Relevance of the trace is questioned	Swab on the skin of the victim, matrix is known to give a positive result and even a hit, but matches the victim's profile
2	4	1	Relevance of the trace is questioned	Object recovered in the hall way, other objects found on the escape route were considered more relevant
3	9	6	Same matrix as other analysed traces which did not yield a profile	Swab on the skin of the victim, matrix is known to give a positive result and even a hit, but matches the victim's profile
4	2	1	Probably victim at the source of the trace	Potentially blood trace originating from the victim found at the bottom of the staircase of the building where the victim was violently hurt
5	4	1	Same matrix as other analysed traces which did not yield a profile	Trace recovered from a box, another box in the same case did not yield a positive result
6	2	1	Probably victim at the source of the trace	Tool that was allegedly used to hit the victim. Blood trace potentially originating from the victim
7	3	2	Same matrix as other analysed traces which did not yield a profile	Inside a vehicle, other traces inside the same vehicle yielded a complex mixture
8	9	2	Same matrix as other analysed traces which did not yield a profile	Shoelaces were analysed, did not yield a positive result, the heel was thus not analysed
Total	40	16		

a suspect was known in the case or not, the cases without suspect identification were of particular interest regarding the not analysed traces. The question at hand is whether these types of cases, which did not yield the identity of a suspect (45 of the 101 cases had no suspect identification *a posteriori*), contain unanalysed traces and, if so, what were the reasons for the non analysis.

In total, 8 cases could be identified belonging to this category, with a total of 16 unanalysed biological traces. Through a detailed case study, it was understood why these traces remained unanalysed; for all of the unanalysed traces explanations for their non-analysis could be found. Two main reasons could be determined (see Table 7.3): (1) the unanalysed trace was collected from a similar matrix than other traces in the case, whose analyses did not yield a useable profile, (2) the crime scene investigators inferred, through the context information, that the trace probably originates from the victim, and thus the trace is considered not relevant.

The identified reasons seem absolutely legitimate although no information is thus far available in the case regarding the identity of the offender(s).

Case example A robbery was committed in a little village store. Two men entered the store, one pointing a gun at the shop owner, the other one throwing an unidentified liquid on her. The shop owner fled from behind the cashier's desk to the corner of the store. Both men moved behind the cashier's desk, opened the cashier, grabbed the money and fled. New customers came into the shop after the events, and were served. When the crime scene investigators arrived, several police men were present, inside the shop. According to the testimony given by the shop owner, a handful of people had already touched the cashier's desk that same morning, and the floor had been cleaned the day before. Due to all these sources of pollution and background, the forensic investigation for relevant and pertinent traces proved to be difficult. Yet, two swabs for biological traces were performed at the cashier's desk, one on the screen and one inside the drawer. In addition, the shop owner's t-shirt was collected.

The police performed their enquiry, and, four men, living just down the road from the shop, could soon be questioned in relation with the events. Although no shoe marks had been collected (due to poor quality, but had been searched for and some could be distinguished), the police asked the crime scene investigator to check the patterns of the four men's shoes. No definite result could be stated to the police. Two of the four men could soon be released, as no incriminating information could be found.

Back in the office, the crime scene investigator decides to wait with the analysis of the biological traces until next week. Indeed, the traces are submitted to the laboratory every Wednesday (except for the traces in 'urgent' mode). This case happened on a Wednesday morning, thus, the biological traces would anyway only be transferred to the lab the following week. He actively withheld the analysis to wait for the traditional police enquiry to yield results. He calls the police investigators the next week to be updated about the progression of the case. The expected utility of these clues is for identification purpose, however its evaluation is medium high: due to the link with the activity of taking money from the cashier's desk, the relevance is presumed to be high, however, the pertinence is low as the risk for pollution is high, and thus, the chance for obtaining a positive result from that trace analysis is lowered.

Regarding the t-shirt, however, he decides to submit it immediately for analysis to identify the unknown substance. From this information, he expects to give the prosecutor information regarding the qualification of the case. The hypothesis is that if a flammable liquid was thrown at the shop owner (and the gun would have been shot), the seriousness of the case increases.

During the search of the two men, the money could be found in the cloths of one them. The traditional police work is successful, the two men still in custody confess. In addition, they confess that they used a flammable liquid to throw at the shop owner. In the end, the analysis of the t-shirt was not performed, as it was considered unnecessary/not useful anymore in the case. Similarly, the biological traces are not analysed either.

In summary, the collected traces that were considered to be pertinent and potentially useful during the crime scene investigation, lost their utility (without considering the utility of confirmation) in the eyes of the crime scene investigator, police investigator and the prosecutor (as they worked in close collaboration) compared to the suspects' confessions.

7.4 Discussion

When considering the utility of the clue in order to measure the performance of forensic science in the investigation, one has to acknowledge various facets or dimensions of its utility. The most common utility is suspect identification. Overall, in 16 out of 101 cases, the analysis of biological traces or fingermarks led to the first information regarding the suspect's identity. In terms of utility, forensic science did not have the chance to deliver this information in 15 cases, that were solved through police enquiry even before the analysis of traces could have been performed. Hence, the actual identification utility of forensic science lies at 16 out of 86 cases, i.e. 19%.

The utility of forensic science goes however beyond the identification of suspects.

Indeed, in 13 cases, the suspect's identity could be confirmed through trace analysis. This means that in 13 cases, a suspect was determined through police enquiry (prior or subsequent to trace analysis), and a hit with this suspect could be reached through trace analysis confirming thus his implication. Contrarily, to what is found in the literature, the main contribution of forensic science is thus not to build the case against the suspect rather to confirm the circumstances/their implication.

Through a detailed case study, it could be determined that there were reasonable justifications for the remaining non-analysed traces in unsolved cases. In some cases, traces on the same matrix had been analysed, but did not yield a positive result, and thus, it was decided not to continue analysing traces from that matrix. In other cases, the inferred sources was attributed to the victim, leading to a drop in the evaluation of the relevance of the trace.

Last, but certainly not least, one needs to consider the crime linking capacity of traces. Traces contributed to crime linking in 21 cases: 18 through biological traces, 2 through fingermarks and 1 through shoe marks. In two cases, the suspect could be excluded through police enquiry. The study of the recidivists can lead to a study of the aggravation of the sentence due to the knowledge of the crime links. However, this is out of the scope of this study. This information can also increase the knowledge about criminal careers of offenders. This crime linking capacity of forensic science demonstrates that forensic science can contribute specific, actionable intelligence on the number of individuals committing crimes, the movement of an individual from one type of crime to another, and the geographical location of these individuals, identified or not. This argues for a drastic expansion of forensic science use in order to feed data to that side of policing.

8 Discussion

8.1 General discussion of the impact of the research project

On the one hand, forensic science is praised as being this omnipotent tool to help solve crime, shaping the perception of its role and the expectations of its contribution in the courtroom. On the other hand, policy makers recurrently question its performance and its actual contribution to the criminal justice system, and more particularly to the criminal investigation. Studies attempting to measure the effectiveness or efficiency of forensic science multiplied, revealing a diversity in the understanding and definition of forensic science, its role and above all, its actual contribution to the criminal justice system.

One main aim of the study was to formalise the decision-making process with a particular interest for the decision to analyse a trace. The reasoning and usage processes of the traces in the criminal investigation were determined and the complex picture obtained through this descriptive approach highlights the difficulty to reach a normalisation of the object of study. The decision to analyse a trace is context-dependent, case-specific and embedded in a complete decision-making process involving many different actors. Based on our findings, the efforts to implement guidelines, based on the generalisation of the cases and the factors involved in the decision-making steps for different types of crimes and different types of traces, are difficult to justify in this highly complicated and entangled environment. This point emphasises the absolute need for education of crime scene investigators and investigators in not merely the analytical capabilities of traces, but of the many different ways in which forensic science can assist the law enforcement effort.

The isolated consideration of the decision to analyse a trace, or any other step of that decision-making process, from the rest of the criminal enquiry, hinders the integration of the utility of the clues to the case when using forensic science. However, under the 'structural' integration model, the role of forensic science is commonly understood as and limited to the assistance of court through the application of scientific techniques, epitomising forensic science as the analysis of the trace, without considering the context in which it is used, the reasoning processes and the decision-making process involved. The decision-making steps are considered individually and independently, guided mostly by managerial, actuarial rules, which leads to a partial and external view of the use and usefulness of forensic science. The decision-making steps are dependent on each other, in both ways: the latter decision steps depend on the earlier ones, but also, the anticipation of the latter decision steps influence the earlier steps. The triaging affects the possibility to use a trace later in the process. Whereas the anticipation of its use can guide the decision to collect or analyse a trace. This dependence calls for an holistic view of the complete process within a generalist perspective of forensic science. The trace needs to be the central element forwarded through the decision-making process in a utility perspective, both to the case and, in a broader sense, to the general security issues.

Contrarily to the decision-making process, the criminal procedural system in place varies greatly in space and time. It shapes the role of forensic science, its actors, and users. In accusatorial systems, the prosecutor has to build the case against a suspect and find proof (Ramsay, 1987; Horvath and Meesig, 1996). All instances involving the use of forensic science are separated in order to avoid evidence tampering and bias. The analysis of a trace is often perceived as purely technical step, with the decision to analyse relying solely on technical quality aspects of the trace. In this scattered view, the different decision steps are made by different actors and, in the same sense, are evaluated independently. Not surprisingly, their results tend to indicate that the reason for use of forensic science is to build a case against a suspect, and, thus, the contribution of forensic science to the progression of the case is small, compared to witness testimony for instance (Baskin and Sommers, 2010).

When however recognising the imbrication of the decision-making steps in a complete process, one can get an understanding of the reasons for case and trace attrition. As could be determined, the results of the attendance strategies in three different cantons varied a lot. This variation, or rather, the attendance strategy needs to be taken into account when evaluating the decision to analyse a trace, as the decision to attend a crime scene precedes the decision of interest, and it is thus influenced by its result. Same applies to the decision to search for and to collect traces, and the resources allocated to this step, in terms of available material and techniques, but also the knowledge and training given to the crime scene investigators. All these choices influence the perception of the usefulness of forensic science, its use and finally its performance.

In inquisitorial systems, the collaboration between the police and the prosecutor's office is of high importance. The latter have a broad range of competencies in deciding how investigations are conducted. In the Swiss context, forensic science is integrated in the criminal procedure, and, the crime scene investigators collect traces, analyse some of them, weight together their results and share this information with police investigators and/or prosecutors in charge of the case. The collaboration and communication between the prosecutors's office, police and crime scene investigators shape the way in which traces are used and the assessment of the expected contribution. This information flow allows to readjust the expected value of the traces in the case, and thus, guide the decision-making regarding the analysis of the traces to contribute to the case. Observations made during participation revealed that the collaboration model relies mostly on the human factor, i.e. interpersonal relationships, and is performed in an informal way. Except for homicide cases, very few formal procedures exist to regulate and promote the information flow and communication between the different actors. As *utility* was determined to be a central element in the decision to analyse a trace, and thus, the information previously available is taken into account at this stage, regular updates on case progress between all actors of the criminal justice process are essential. A detailed analysis of the situation at hand regarding the collaboration and the communication of the different actors would be beneficial and potentially lead to the implementation of a structured exchange of information with the aim of a more informed and utility-based decision-making.

Through a similar approach, the consideration of the criminal dimension could be enhanced. The knowledge of linked cases influenced the decision to analyse a trace, as demonstrated through its importance in the decision tree model and the experiences observed during the participant observation. This factor, in particular, relies on the integrated model, conceiving forensic science in a broader intelligence perspective. The crime link needs to be detected, requiring an overlapping information base of national and international cases, and this information needs to be timely divulged to the relevant decision-makers regarding trace processing.

Physical dimensions are often praised when discussing the decision factors of the traces to submit for analysis. Indeed, this factor is straightforwardly measured and sometimes transformed into a guideline, with the statistics on success rates per matrix or type of biological trace ('rich' versus contact trace) or DNA concentration (Mapes et al., 2016), serving as decision factors. In high-volume crimes, such as burglary cases, the focus is often set on 'rich' biological traces (regardless of the frequency of finding these types of traces from the offender in burglary cases). From this choice, the policy makers hope to yield a great success rate when analysing these traces. Similarly, the matrices are codified and selected according to their respective success rate. However, these factors fall short of the actual contribution of biological traces. For both factors, the hit rate or rather the pertinent hit rate is not considered in the equation. What is the utility of obtaining many positive results, if most of them, match the victim (where one wanted to link the suspect to the scene)? We also need to consider the traces, or matrices, that we exclude through such a shortsighted view. Traces on some matrices give rarely a positive result, but when they do, the profile matches the suspect's profile. The question is: do we want to 'optimise' our analysis strategy in regards to the analysis results thus far to exclude potential hits and thus miss investigative leads, instead of optimising the utility of the clues? When excluding these traces from analysis, the contribution of forensic science to the criminal justice system is increasingly weakened. In addition to the question about the right indicator (success rate versus hit rate), this study reveals some concern regarding the use of success rate as information: we have seen that the success rates of 20 of the overall 30 different matrices examined vary enormously over the period of 3 years. When taking an average of the success rates, this variation is lost and seems to indicate flawlessly whether a matrix is a 'good donor' or not. Nonetheless, this factor is not reliable for 2 out of 3 matrices. These results tend to indicate that the analysis choice based on the matrix of the trace is mainly oriented towards considerations of economical justifications. Whereas, the observation of the practical reality (bottom-up, i.e. the circumstances of the case) promotes the consideration of the utility of the clue for the case in question. The doctrinal guidelines, at least partially, restrain the contribution of forensic science in the criminal investigation, instead of valorising it. Yet, this study shows that forensic science plays an important role at this stage and hindering its use would result in the loss of potentially valuable information to the investigation, regardless of whether the clues will be considered as pieces of evidence during trial at a later stage.

Looking solely at the impact of forensic science on judicial steps neglects the reasons for case and trace attrition that occurred earlier in the process. The decision to analyse a trace is extracted without considering the initial decision steps. As was noted previously, an holistic view is needed when considering the use of traces in the criminal justice process, and especially in the criminal investigation. When assessing the contribution of forensic science in this process, it is thus more important to recognise the complete picture. The effectiveness determined at each stage and for each type of trace individually can not be generalised to the overall contribution of forensic science. Through the consideration of the individual contributions and or limitations at each stage, the overall utility is missed.

The decision to analyse a trace should be considered in the perspective of the *problem to find*, rather than the *problem to prove* (Kind, 1994). The focus on the judicial phase, concerning mainly the problem to prove, limits the analysis of traces in regards to the probative value of its result. However, the problem to find is less restricted, and consists in finding investigative leads to increase the knowledge and understanding of criminal phenomenon in general or a particular enquiry. This strategy should be followed providing information to work with, at the risk of this information being uncertain, and, similarly, this perspective of information gain needs to be applied when measuring the performance of forensic science. Considering the *problem to find* opens a whole new dimension from which additional and likely highly valuable information about criminal phenomena (i.e. linking cases) can be drawn.

When attempting to measure the contribution of forensic science to the criminal justice system, or more precisely the criminal investigation, one has to take into account all types of traces (from the 'gold standard' biological traces, over fingermarks, to shoe marks and all other traces) with all facets of their potential contribution (identification, confirmation, crime linking, reconstruction, implication, etc.). Most of the studies summarised in the literature review consider one or two types of traces (mainly biological traces and fingermarks). However, the other ones must not be neglected, especially when considering contributions such as their crime linking potential. Admittedly, this study focussed on cases with at least one collected biological trace. This was however necessary in order to investigate the influence of different decision factors on the decision to analyse a trace, in the specific case of biological traces. Nonetheless, the contribution of other traces could be highlighted especially in the participant observation phase, and through the investigation of the sequence of analysis of biological traces to fingermarks or shoe marks.

Conversely, in order to reach the full contribution range of forensic science, all types of traces need to considered and exploited in the criminal investigation, at the different decision-making steps. The focus on one type of trace (often biological traces) at the expense of all other types of traces is detrimental to potential information gained through other traces. This is clearly demonstrated by our study revealing that the results of previously analysed traces were considered important in the decision to analyse a trace. Thus, this information needs to be divulged between specialist sections, when applicable, and handled by a generalist having the overview of all available traces, performed analyses and results. The most promising contribution of forensic science can be reached in the succession of the crime scene investigation, with the inclusion of its multitude of traces, generalist approach and reasoning around the circumstances of the case.

Overall, the diversity of the dimensions of utility of forensic science to the investigation is recognised by the crime scene investigators as well as by the prosecutors in charge of the case. According to the results regarding the decision to analyse a trace, the main utility of forensic science, especially biological traces, is for suspect identification. In 19% of cases, where no suspect identification was yielded through police enquiry previous to trace analysis, the results of trace analysis delivered the first lead to the suspect's identity. In 15% of cases, the suspect was identified through police enquiry previous to trace analysis.

Other dimensions could be determined qualitatively, such as the determination of the implication of the suspect (who was the one that hit the victim?), legal qualification of the offence, pointing towards other potential locations of traces. Although these dimensions were observed anecdotally (limited number of observed cases), they contribute to the overall value of forensic science and form thus an entire part of the subject of this study.

The *expected* utility of a clue at the moment of decision-making for analysis needs to be considered when assessing and evaluating the use of forensic science in the criminal justice process. As was determined for several cases, the initial *expected* utility of the clue was for identification, however, the police enquiry delivered the name faster, which eliminated thus this dimension from the utility *a posteriori* of the clues. This is not to say that the clues were thus useless. When considering other dimensions of utility as described above, these same clues can still add value to the case. Nonetheless, the shift between the *expected* and the *actual* utility of the clue should be considered to assess the importance of the decision to analyse a trace. This approach needs to be considered in the perspective of each individual trace compared to all other traces in the same case. Thus, submitting ten traces for analysis with the *expected* utility of identification is not considered useful, when knowing that only 1 offender committed the crime. This weighting of the *expected* utility of one trace versus another one in the same case equates with the prioritisation of the traces and is very difficult to study and to assess in hindsight. Due to the limited number of observations during the participant observation phase, it was not possible to study this aspect in detail. The appreciation of the *expected* utility is a dynamic process, highly dependent on circumstantial information and, as such, should be carried out by a forensic science generalist, namely a forensic scientist.

8.2 Limitations and perspectives

The decision to analyse a trace and especially the decision to analyse a trace first appeared to be very complex, context-dependent and case-specific. Further studies need to be undertaken to better understand and decipher the decision factors and their interactions involved in this decision-making step. In addition, the sample being relatively restricted, the study should be repeated on a bigger scale and extended to different types of offences.

The focus on robbery cases committed in the canton Vaud limits the universality and generalisability of the obtained results. The findings of this study are highly dependent on the police structure at hand and on the type of offence. High-volume crimes are certainly handled differently, due to different constraints: their high number, the limited resources (time but also money), the training of the crime scene investigators handling these cases, etc. Although it was noted that robbery cases are a sort of hybrid form, between burglary and homicide cases, regarding the analysis strategy, it would be highly interesting to investigate in detail these two types of offences separately. This is why the study about the utility of the clue should be extended to other types of crimes and their trace processing strategies, as well other cantons and even other jurisdictions.

The study of the influence of the matrix on the success rate can be even more detailed through the consideration of the number of loci obtained from the analysis or the distribution of single, mixed and complex profiles obtained, instead of looking at positive versus negative results. In the scope of this study, it was considered not necessary to detail this result as the perception of the crime scene investigators was of interest. As could be noted during the participant observation phase, the crime scene investigators do not necessarily put their focus on the exact result, but are interested in knowing whether their trace analysis was successful or not. However, in order to generate more precise results of the success rates of the trace analysis of the different matrices, it would be very interesting to include these details.

Another limitation of this study is that the coding of some of the variables was performed manually. And although, throughout the data collection period, the work has been double-checked, errors might still persist.

The participant observation phase was performed in a mainly exploratory manner, i.e. it was unclear at the start what information could be retrieved and in what way this information could contribute to the understanding of the decision-making process. Thus, particularly the participant observation phase should be extended in order to collect more information regarding the decision-making process. As the number of observed cases was very limited, only scattered information could be provided here. In order to determine trends, the same behaviour must be observed multiple times.

A study formalising the integration model, with particular interest on communication and information flow should be envisaged in order to determine potential barriers to the application of the concept of utility. By repeating this study in a framework with a different integration model (e.g. more isolated use of each type of trace and scattered decision-making), it can be evaluated how the communication and information access influence trace processing, the consideration of utility of the clues in decision-making and the actual utility of clues in the investigation. In addition, the implicit hierarchy between the different actors can be evaluated and taken into consideration when studying the decision to analyse a trace.

Regarding the performance study, the contribution of forensic science to the case was evaluated on a case basis, without considering if multiple traces were analysed per case. Supplementary studies need to be performed assessing the contribution of one trace versus another within the same case and thus assessing the expected utility of the clues in one case. The best methodology to reach this objective probably implies participant observation, as it is very difficult or even impossible to determine, by a retrospective approach, the relative value of two similar traces in one case. In addition, similarly to factors involved in the decision to attend a crime scene described by Hazard (2014), the human factor, comprising elements such as the motivation, knowledge, interest for traces, needs also more attention as it is a factor deeply influencing all the decision-making steps in the criminal investigation.

The applied methodology also presents some limitations inherent to the several approaches that were combined. The main inconvenience of the interview is probably the human factor. The questioned person can answer how she wants or what she perceives as being the right answer, instead of reporting what really happens. In addition, each investigator acts in a different way, and thus, the collected information will not be exhaustive. Yet, this research method allows us to collect numerous information, especially about the organisation of the police, the internal guidelines of the forensic unit, the information not available in the case file database of the forensic unit and the subtleties behind the variables in the database. Similarly, the main limitation of participant observation is the lack of exhaustivity. Indeed, only a limited number of cases could be followed during this phase. This analysis method allows us however to familiarise with the routine work of the crime scene investigators and to understand the decision-making process. Thus, some uncertainties encountered during the quantitative data analysis procedure can thus be explained. In addition, through the direct immersion into the world of the crime scene investigators, the researcher can engage in discussions with them and understand the organisation and structure of the police and their interactions.

The mixed methodology applied enriched however the interpretation of the obtained results. The right approach encompasses both quantitative and qualitative research methods, in order to grasp all facets of the contribution of forensic science. Due to the complex nature of the object of study, qualitative research methods were particularly useful to collect information of the cases and determine the influence of their circumstances to the decision to analyse a trace. The case study approach highlighted the individual contribution of forensic science to the case in question.

In a broader policing perspective, the performance of forensic science should also be considered in a security approach (Ribaux et al., 2015a), with its contribution to crime reduction through prevention for instance. The knowledge of crime links through trace analysis can contribute to such an approach as it allows us to increase the knowledge about criminal careers and criminal networks.

9 Conclusion

With increasing pressure to improve performances of the criminal justice and, simultaneously, reduce its costs, the expectation for an efficient and rapid justice is ever-increasing. Inevitably, due to a technology-driven trend, the expectation towards forensic science is increasing. In parallel, the latter is criticised regarding its efficiency, the lack of studies concerning its scientific foundation and its costs that limit its use. Facing that situation, new models need to be developed in order to assess its contribution to the criminal justice system, and in particular to the investigation. Exactly that constituted one of the aims of this thesis.

According to the performance indicators that are currently used to measure the contribution of forensic science in the judicial inquiry, the infrequent use of forensic science is considered as the manifestation of a low performance of the investigators regarding the use of traces. However, a correct appreciation of the utility of clues to the case appropriately limits and redistributes the use of traces in the investigation. This could be determined through the formalisation of the decision-making process of the criminal investigation and particularly the decision to analyse a trace that allowed us to increase the understanding of the multidimensional combination of factors involved in this decision. Utility is based on the relevance of the trace to the case and the pertinence of that trace to the user, who must be capable of using the information extracted from the trace, i.e. the clue. For the clue to be considered useful, it must be relevant and pertinent, and add value in terms of information to the case. The addition of this information needs to change the *status quo* of information already available in the case. Thus, the utility of the clue depends on the information potential of the trace itself, the knowledge of the crime scene investigator and the information previously available.

The applied methodology, combining quantitative and qualitative approaches, enabled to focus on the decision-making process related to the decision to analyse a trace and to decipher the factors affecting it. The crime scene attendance rates of three Swiss cantons were examined and appeared to vary hugely, depending on the strategies, resources and constraints, in place. Robbery cases were determined as being a hybrid form between burglary and homicide cases, regarding their number of collected traces and the corresponding analysis rates. Through decision tree modelling, the decision path could be followed to understand the influence of the different variables. All of the suggested dimensions (strategic, immediate, criminal, physical and utility) were represented in the decision tree models. Particularly the influence of the utility dimension, referring to previous knowledge available in the case, is emphasised. In addition, the variables that are mostly stated in the literature to guide the decision to analyse a trace, notably the financial aspect (which is often mentioned for high volume crimes) and the physical aspects of the trace (the type of biological trace and the matrix it was recovered from) could not be confirmed in this study.

By extension, the appreciation of the utility *a posteriori* of the clue, after the analysis have been performed, showcased the variety of utility dimensions forensic science can portray. The mainly recognised utility dimension is for suspect identification, which was also shown through the study of the decision to analyse a trace; traces are predominantly analysed when no information regarding the suspect's identity is known. Hence, the utility of the DNA database for identification is understood and used. Contrarily to what is found in the literature, the principal aim is not to confirm the suspect's implication through trace analysis, but rather to provide new leads or to reconstruct events, which help determine the seriousness of the case for instance. This finding might be a consequence of the favourable context for DNA analysis in Switzerland, where the traces are analysed within several days. Hence, the problems associated with laboratory backlog are not applicable. In addition to identification and confirmation which is valid mainly for biological traces and fingermarks, the dimensions of the utility *a posteriori* of all clues include the determination of the distinct implication of the different offenders, the reconstruction of the events, the aid in the determination of the seriousness of the case, the exclusion of suspects, the catalyst of information in the enquiry (e.g. in interrogations), the catalyst of traces during the crime scene investigation. When considering a broader policing approach, additional utility dimensions concerning their contribution to the wider security perspective in terms of prevention of crimes need to be taken into account.

The decision to analyse a trace, and particularly the decision to analyse a trace first (when multiple traces have been collected in the case) appeared to be very complex, context-dependent, limited by the situation and case-specific. As a result, it seems very difficult and hardly relevant to standardise this decision by rigid managerial rules. Having said that, the findings of this thesis are difficult to generalise to other types of crimes. The descriptive approach shows the limitations of the efforts to normalise the decision-making process.

Limiting the study of the performance of forensic science to a purely judiciary role as the assistance for court understates the actual contribution of forensic science to the complete criminal justice system. Acknowledging however the role and integration of forensic science in the criminal justice system, starting at the crime scene, with the trace as its central element, the use of forensic science can substantially contribute to case processing and in more general terms to the overall security situation. As could be demonstrated through a case study in this thesis, the facets or dimensions of the contribution of forensic science are manifold, particularly in the criminal investigation.

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A Details about the criminal procedure

A.1 The phases

"The preliminary proceedings comprise the police enquiries and the investigation by the public prosecutor"[1] (Article 299 CrimPC). They commence when either enquiries are begun by the police or an investigation is opened by the public prosecutor (Article 300 CrimPC).

A.1.1 Police enquiries

During the police enquiries, the police has the following duties (Article 306 CrimPC):

1. "The police shall in the course of their enquiries establish the facts relevant to an offence on the basis of reports, instructions from the public prosecutor or their findings.
2. They must in particular:
   a) **secure and evaluate forensic and other evidence**;
   b) identify and interview persons suffering harm and suspects;
   c) if necessary, stop and arrest or attempt to trace suspects."[2]

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[1] Official version in French: "La procédure préliminaire se compose de la procédure d'investigation de la police et de l'instruction conduite par le ministère public."

[2] Official version in French:

i. "Lors de ses investigations, la police établit les faits constitutifs de l'infraction; ce faisant, elle se fonde sur les dénonciations, les directives du ministère public ou ses propres constatations.
ii. La police doit notamment:
   A. mettre en sûreté et analyser les traces et les preuves;
   B. identifier et interroger les lésés et les suspects;
   C. appréhender et arrêter les suspects ou les rechercher si nécessaire."

According to Article 307 CrimPC, a cooperation with the public prosecutor takes place. “The police shall inform the public prosecutor immediately of serious offences and other serious incidents.”[3] The public prosecutor may issue instructions and assignments to the police at any time or take over the conduct of the proceedings.

A.1.2 Investigation by the public prosecutor

In Article 308 CrimPC, it is stated the definition and purpose of the investigation by the public prosecutor. “In the investigation, the public prosecutor shall clarify the factual and legal aspects of the case in order to conclude the preliminary proceedings. [...] If charges are to be brought, the investigation must provide the court with the basic information required to assess the guilt of the accused and to impose a sentence”.[4]

“The public prosecutor shall gather the evidence themselves” (Article 311 CrimPC)[5]. “The public prosecutor may instruct the police to carry out additional enquiries after the investigation has been opened” (Article 312 CrimPC)[6].

According to Art 309 CrimPC, “The public prosecutor shall open an investigation if:

a) there is a reasonable suspicion that an offence has been committed based on the information and reports from the police, the complaint or its own findings;

b) it intends to order compulsory measures;

[3] Official version in French: “La police informe sans retard le ministère public sur les infractions graves et tout autre événement sérieux.”
[4] Official version in French: “Le ministère public établit durant l’instruction l’état de fait et l’appréciation juridique du cas de telle sorte qu’il puisse mettre un terme à la procédure préliminaire. [...] Dans le cas d’une mise en accusation, l’instruction doit fournir au tribunal les éléments essentiels lui permettant de juger la culpabilité du prévenu et de fixer la peine.”
[5] Official version in French: “Les procureurs recueillent eux-mêmes les preuves.”
[6] Official version in French: “Même après l’ouverture de l’instruction, le ministère public peut charger la police d’investigations complémentaires.”

c) it has received information from the police of serious offences and other serious incidents (in terms of Article 307 paragraph 1)."[7]

The instruction is under the responsibility of the public prosecutor who orders all the necessary instruction measures. The police thus do not act autonomously anymore.

A.1.3 Abandoning Proceedings and Bringing Charges

"The public prosecutor shall order the complete or partial abandonment of the proceedings" according to Article 319 CrimPC.[8] On the contrary, "the public prosecutor shall bring charges in the competent court if, based on the results of the investigation, it regards the grounds for suspicion as sufficient and it is not competent to issue a summary penalty order" (Article 324 CrimPC).[9]

A.2 Prosecution authorities

A.2.1 Public prosecutor

"The public prosecutor is responsible for the uniform exercise of the state's right to punish criminal conduct. It conducts preliminary proceedings, pursues offences within the scope of the investigation, and where applicable brings charges and acts as prosecutor"[10] (Article 16 CrimPC). The public prosecutor assesses the facts and their legal qualification.

"According to the lawmaker, the advantage of such a system is reflected in the greater

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[7] Official version in French: "Le ministère public ouvre une instruction:

a) lorsqu'il ressort du rapport de police, des dénonciations ou de ses propres constatations des soupçons suffisants laissant présumer qu'une infraction a été commise;

b) lorsqu'il ordonne des mesures de contrainte;

c) lorsqu'il est informé par la police conformément à l'art. 307, al. 1."

[8] Official version in French: "Le ministère public ordonne le classement de tout ou partie de la procédure"

[9] Official version in French: "Le ministère public engage l'accusation devant le tribunal compétent lorsqu'il considère que les soupcons établis sur la base de l'instruction sont suffisants et qu'une ordonnance pénale ne peut être rendue."

[10] Official version in French: "Le ministère public est responsable de l'exercice uniforme de l'action publique. Il lui incombe de conduire la procédure préliminaire, de poursuivre les infractions dans le cadre de l'instruction et, le cas échéant de dresser l'acte d'accusation et de soutenir l'accusation."

efficiency of concentrating in the hands of a single body the search of evidence, the investigation and the prosecution." (Borsodi and Ntah, 2010, p.1–2).

From a judicial perspective, once a prosecutor is tied to a case, she is responsible for the case and its progress.

A.2.2 Police

"The police investigate offences on their own initiative, in response to reports from members of the public and from authorities, and on the instructions of the public prosecutor; in doing so, they are subject to the supervision and the directives of the public prosecutor" (Article 15 para 2 CrimPC)[11]. In other words, the police enquire on the offence, collect evidence, secure traces, apprehend and identify the offender to transfer to justice.

A.3 Other actors

This section presents some of the actors involved in the criminal procedure. The ones described here are indirectly involved in the decision to analyse a trace.

A.3.1 Suspect / Accused

"For the purposes of this Code, the accused is a person suspected, accused of or charged with an offence in a report of a criminal offence, a criminal complaint or in a procedural act carried out by a criminal justice authority" (Article 111 CrimPC).[12]

The identification of this actor often defines the passage between the two phases of the preliminary proceedings, from police enquiries to investigation by public prosecutor. It constitutes a pivotal point in the utility of forensic science, from an identification to a confirmation perspective.

[11] Official version in French: "La police enquête sur des infractions de sa propre initiative, sur dénonciation de particuliers ou d'autorités ainsi que sur mandat du ministère public; dans ce cadre, elle est soumise à la surveillance et aux instructions du ministère public".

[12] Official version in French: "On entend par prévenu toute personne qui, à la suite d'une dénonciation, d'une plainte ou d'un acte de procédure accompli par une autorité pénale, est soupçonnée, prévenue ou accusée d'une infraction."

A.3.2 Person suffering harm / Victim

"A person suffering harm is a person whose rights have been directly violated by the offence" (Article 115 CrimPC).[13] "A victim is a person suffering harm whose physical, sexual or mental integrity has been directly and adversely affected by the offence" (Article 116 CrimPC).[14]

The damage inflicted through the acts of the offender to this person will determine the qualification of the case, which might also influence the crime scene investigation and thus the triaging of the traces.

A.3.3 Witness

"A witness is a person not involved in committing an offence who can make a statement that may assist in the investigation of an offence and who is not a person providing information" (Article 162 CrimPC).[15]

The reports by the last two actors can influence the crime scene investigation, and thus, the triaging of the traces. When precise details are giving regarding actions of the offender, the crime scene investigation can focus on the described elements. In addition, they will affect the relevancy of the traces searched and collected by the crime scene investigator, and thus, will be most probably be considered during the triaging of the collected traces.

A.3.4 Authorised experts

According to Article 182 CrimPC, "The public prosecutor and courts shall request the services of one or more expert witnesses if they do not have the specialist knowledge and skills required to determine or assess the facts of the case".[16] This expert witness shall conduct technical analyses, on demand of the police and/or the prosecutor.

[13] Official version in French: "On entend par lésé toute personne dont les droits ont été touchés directement par une infraction."

[14] Official version in French: "On entend par victime le lésé qui, du fait d'une infraction, a subi une atteinte directe à son intégrité physique, psychique ou sexuelle."

[15] Official version in French: "On entend par témoin toute personne qui n'a pas participé à l'infraction, qui est susceptible de faire des déclarations utiles à l'élucidation des faits et qui n'est pas entendue en qualité de personne appelée à donner des renseignements."

[16] Official version in French: "Le ministère public et les tribunaux ont recours à un ou plusieurs experts lorsqu'ils ne disposent pas des connaissances et des capacités nécessaires pour constater ou juger un état de fait."

B Details of the data

	A	B	C	D	E	F	G	H	I	J	K	L
1	N_Case	Trace number	Analysed	Batch1	CS_investigation	Prosecutor	TeamA	TeamB	TeamC	TeamD	TeamE	Nb_biol_traces
2	Case1	Case1-Object1-Trace1	1	1	1	1	1	0	0	0	0	14
3	Case1	Case1-Object2-Trace1	1	1	1	1	1	0	0	0	0	14
4	Case1	Case1-Object3-Trace1	1	1	1	1	1	0	0	0	0	14
5	Case1	Case1-Object4-Trace1	1	1	1	1	1	0	0	0	0	14
6	Case1	Case1-Object5-Trace1	1	0	1	1	1	0	0	0	0	14
7	Case1	Case1-Object6-Trace1	1	0	1	1	1	0	0	0	0	14
8	Case1	Case1-Object7-Trace1	1	0	1	1	1	0	0	0	0	14
9	Case1	Case1-Object8-Trace1	1	0	1	1	1	0	0	0	0	14
10	Case1	Case1-Trace4	1	1	1	1	1	0	0	0	0	14
11	Case1	Case1-Trace5	1	0	1	1	1	0	0	0	0	14
12	Case1	Case1-Trace6	1	1	1	1	1	0	0	0	0	14
13	Case1	Case1-Trace7	1	1	1	1	1	0	0	0	0	14
14	Case1	Case1-Trace8	1	1	1	1	1	0	0	0	0	14
15	Case1	Case1-Trace9	1	0	1	1	1	0	0	0	0	14

Fig. B.1.: Example of data for one case: strategic variables.

M	N	O	P	Q	R	S	T	U	V
Business	Private	Service	Camera	Witness_report	Weapon	Violence_victim	NbOffenders	Nb_shoemarks	Nb_fingermarks
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0
0	0	1	0	1	1	0	2	3	0

Fig. B.2.: Example of data for one case: immediate variables.

W	X	Y	Z
Rich_biol_trace	Presumptive_testing	Matrix	Crime_link
0	0	0.28571429	0
0	0	0.28571429	0
0	0	0.28571429	0
0	0	0.68604651	0
1	0	0.56722689	0
1	0	0.56722689	0
1	0	0.56722689	0
1	0	0.56722689	0
0	0	0.39443156	0
0	0	0.765625	0
0	0	0.55172414	0
0	0	0.14285714	0
0	0	0.27777778	0
0	0	0.27777778	0

Fig. B.3.: Example of data for one case: physical and criminal variables.

AA	AB	AC	AD	AE	AF	AG
Suspect_police_inquiry	Nb_biol_traces_analysed	Positive_result	Id_biol_trace	Id_Other	Id_total	Id_Suspect
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	8	1	1	0	1	1
0	8	1	1	0	1	1
0	8	1	1	0	1	1
0	8	1	1	0	1	1
0	0	0	0	0	0	0
0	8	1	1	0	1	1
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	8	1	1	0	1	1

Fig. B.4.: Example of data for one case: Utility variables.

C Decision tree example

The decision of interest is the question whether to analyse a trace or not. The conditions are the independent variables defined in Chapter 6. Depending on the state of the condition (true or false for a binary variable), the sample will be split and the distribution of the analysis rate will change. The conditions to be included in the model are determined based on different selection criteria, depending on the algorithm used to create the model (see subsection 6.3.2 for more detail).

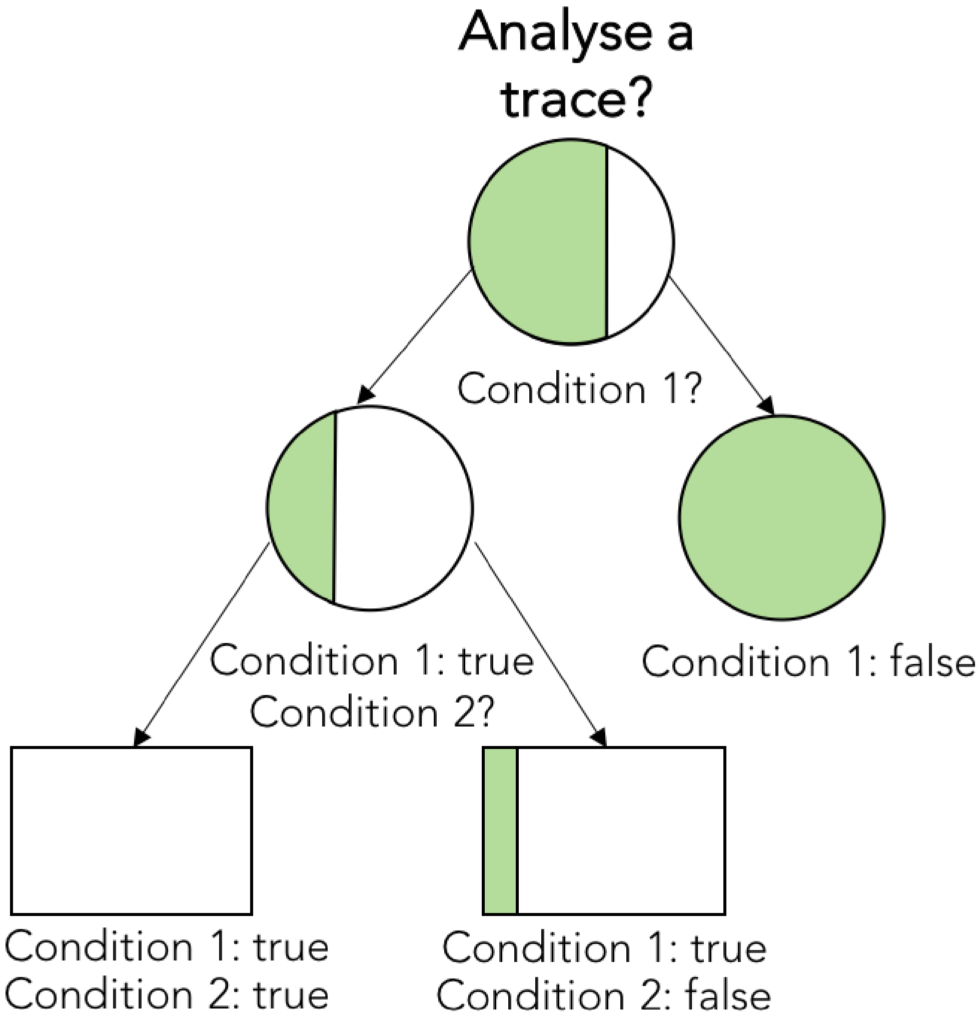

Fig. C.1.: Decision tree example.

Let's assume that at the initial state, the analysis rate of collected traces lies at 74%. When Condition 1 is false, the analysis rate goes up to 100%. No further splitting is required, as a completely homogeneous group has been created. When Condition 1 is true, the analysis rate drops to 27%. Condition 2 is introduced as it splits the data into more homogeneous groups. When both Condition 1 and 2 are true, no traces are analysed. When Condition 1 is true and Condition 2 is false, only a small percentage of collected traces is analysed.

D Supplementary figures

Violin plots of the analysis rates of biological traces, shoe marks and fingermarks in robbery cases in canton Vaud, from January 2012 to December 2013. The representations of the distribution of fingermarks and shoe marks are misleading. One could interpret the wider end for fingermarks (between 0 and 0.8) as representing more values in this range than for shoe marks. However, when comparing with the box plots in Figure 6.8, one can see that, for fingermarks, only 1 value is at 0, and all the other are at 1.

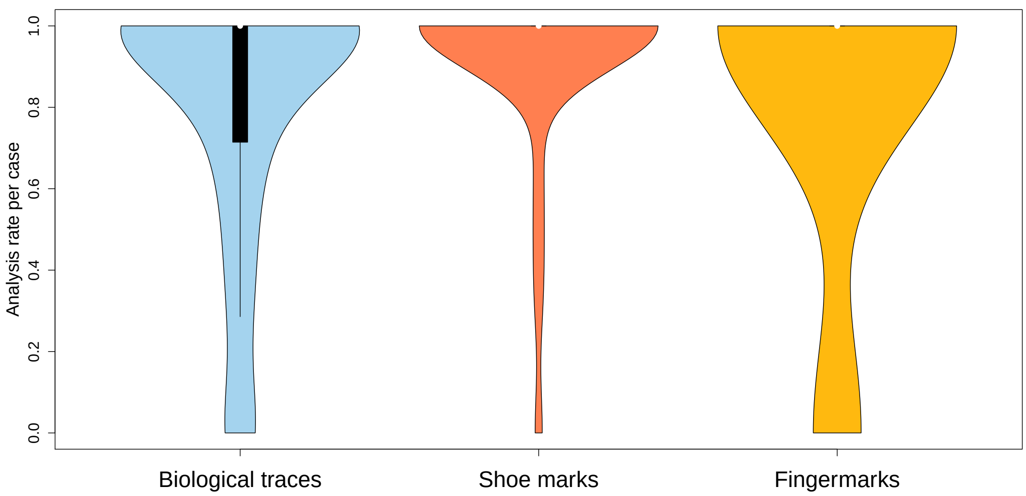

Fig. D.1.: Comparison of the analysis rates of biological traces, shoe marks and fingermarks.

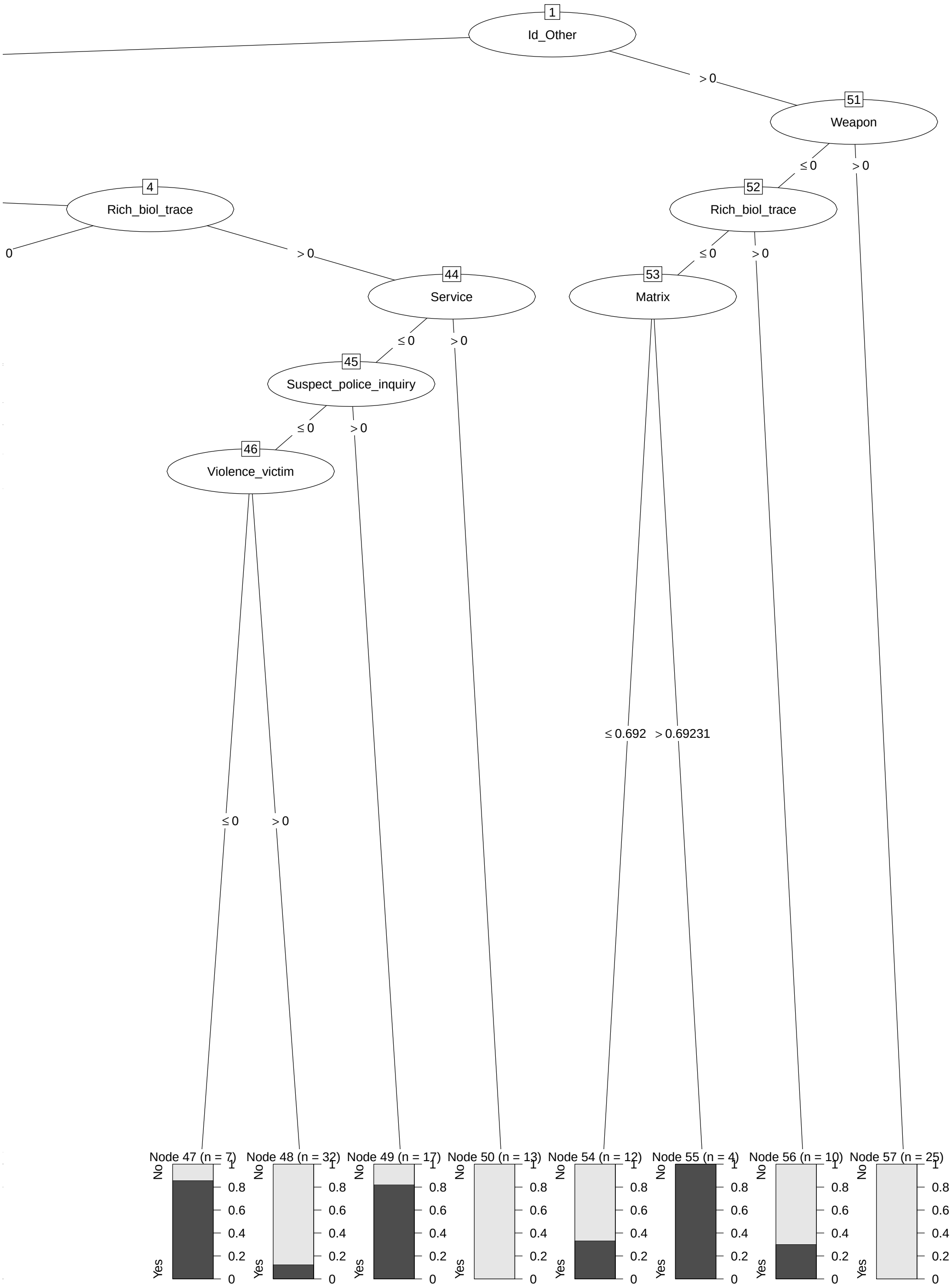

Fig. D.2.: Right part of the C5.0 decision tree model of the first batch analysis.

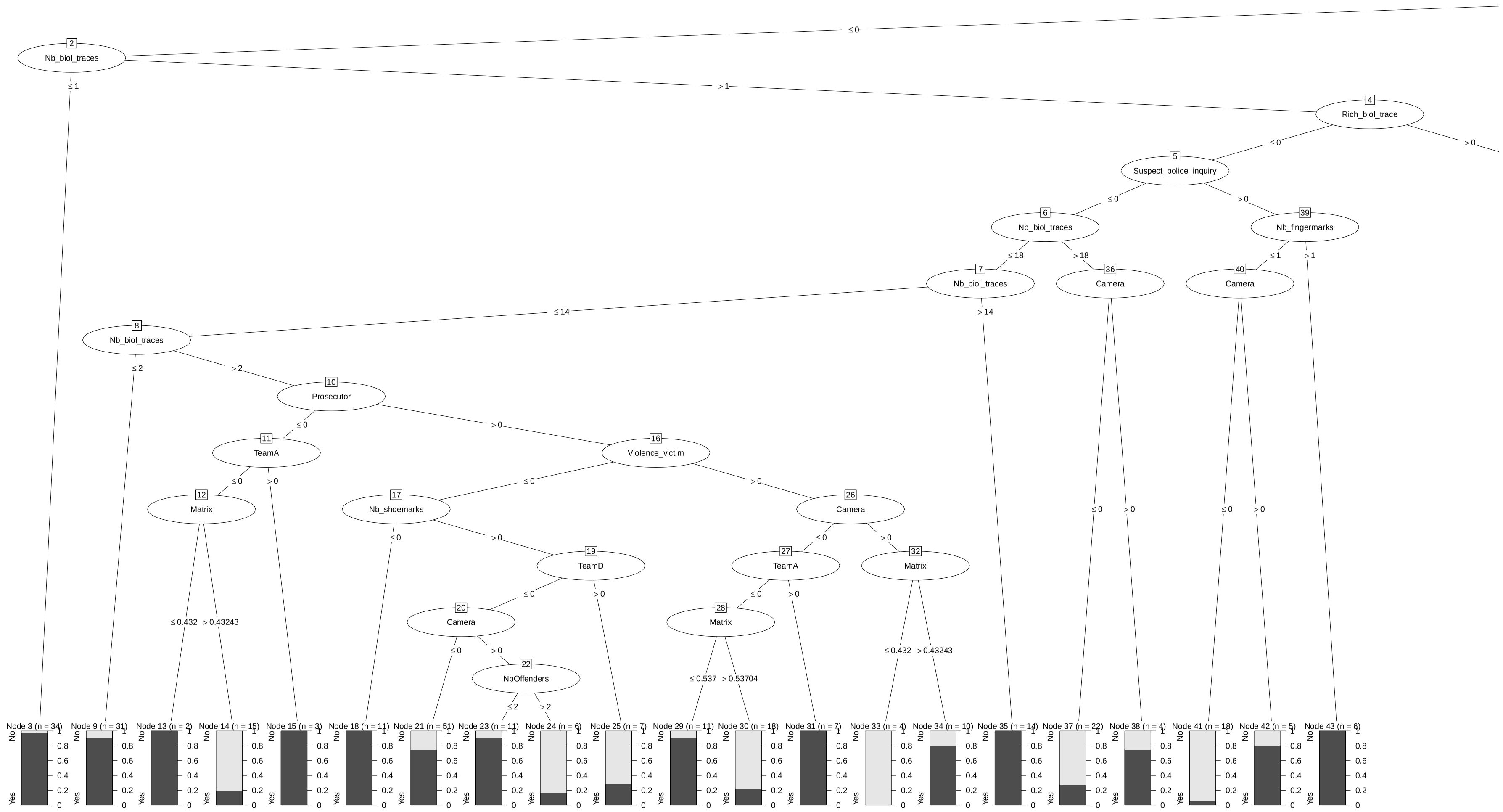

Fig. D.3.: Left part of the C5.0 decision tree model of the first batch analysis.

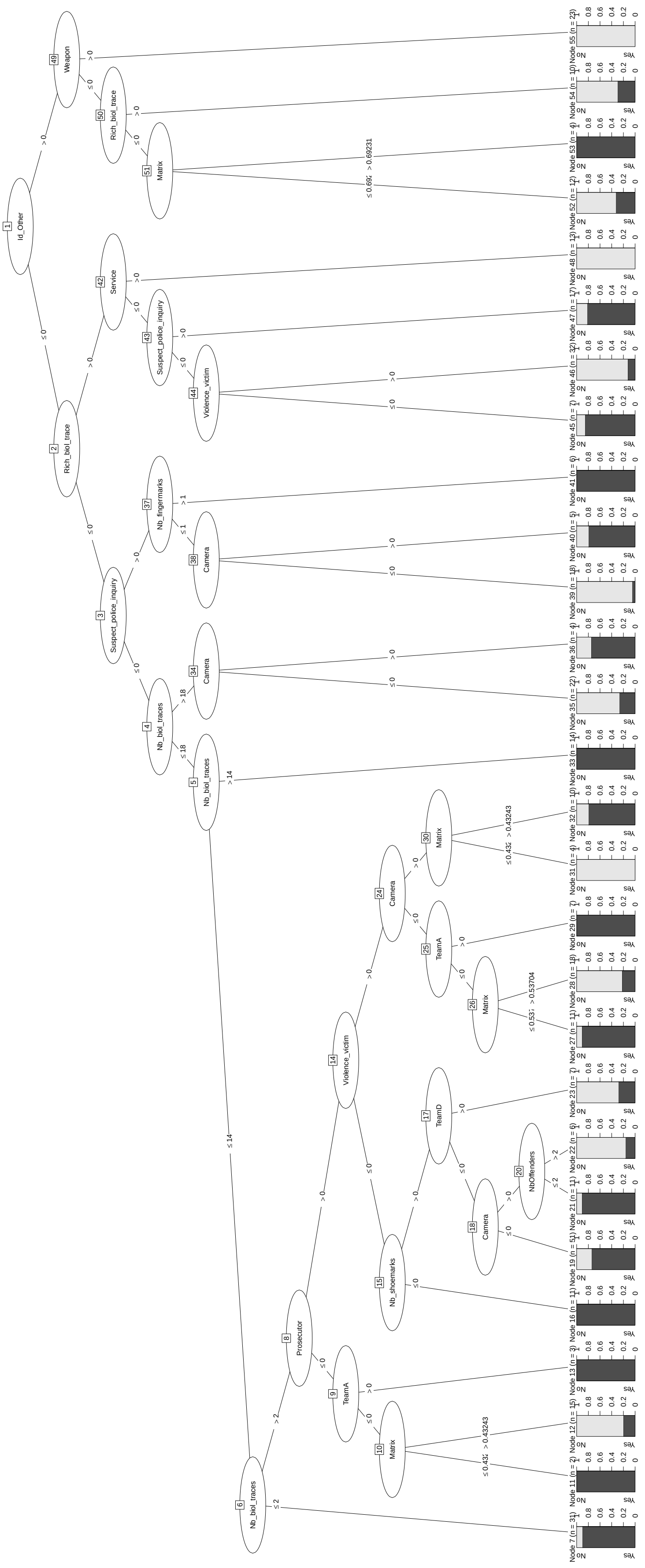

Fig. D.4.: C5.0 decision tree model of the first batch analysis applied on the dataset without the cases with only one collected trace.

List of Figures

List of Tables