Amsterdam University of Applied Sciences

# Rapid DNA Technologies at the Crime Scene

*'CSI' Fiction Matching Reality*

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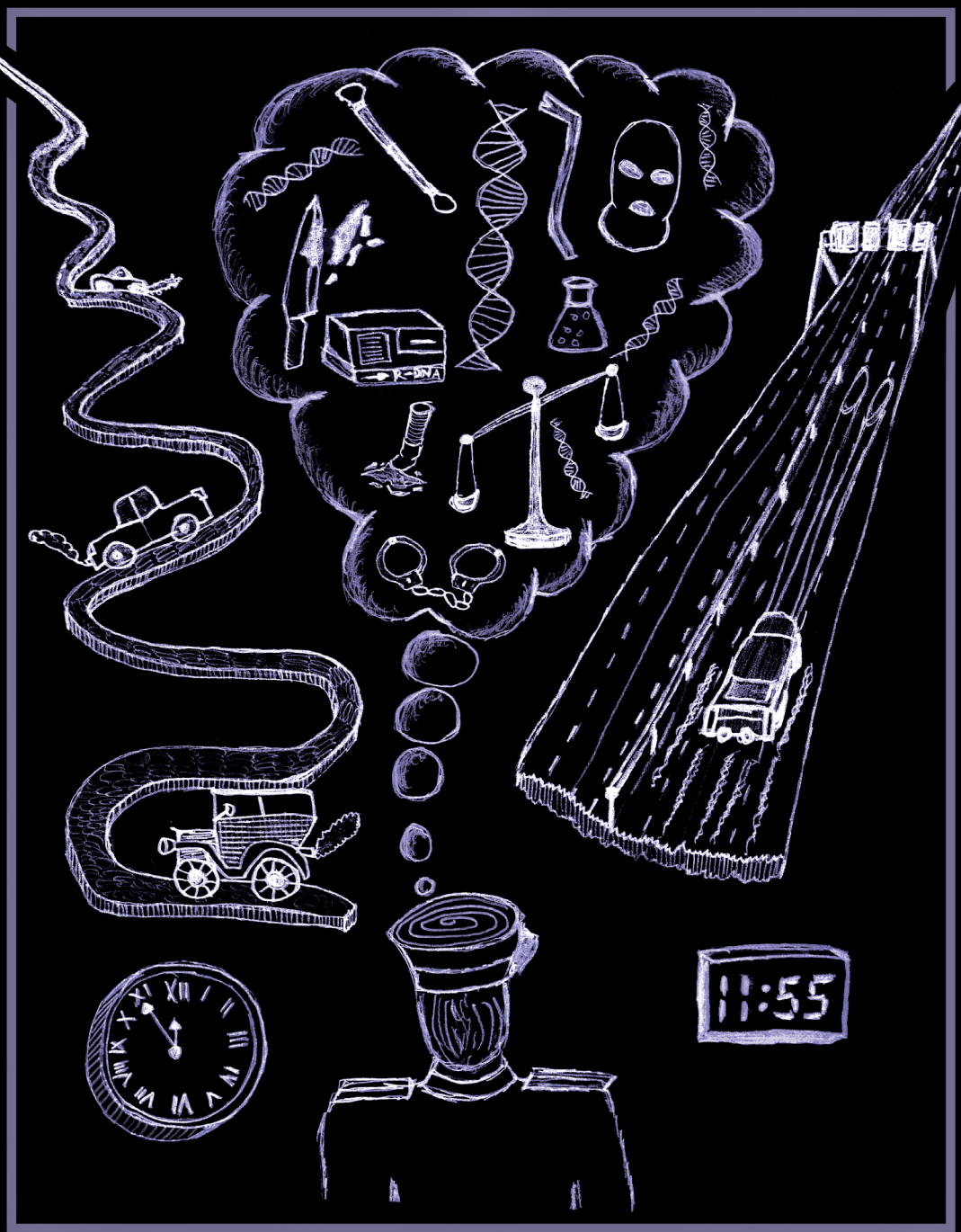
# RAPID DNA TECHNOLOGIES AT THE CRIME SCENE

## 'CSI' FICTION MATCHING REALITY




ANNA MAPES

# RAPID DNA TECHNOLOGIES AT THE CRIME SCENE
# 'CSI' FICTION MATCHING REALITY

Anna Mapes

Rapid DNA technologies at the crime scene - 'CSI' fiction matching reality

PhD thesis, University of Amsterdam IBED, The Netherlands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# RAPID DNA TECHNOLOGIES AT THE CRIME SCENE
# 'CSI' FICTION MATCHING REALITY

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Anna Agnes Mapes

geboren te Taunton, Engeland

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‘Here is my lens. You know my methods.’ What can you gather yourself as to the individuality of the man who has worn this article?’

‘I can see nothing,’ said I, handing it back to my friend.

On the contrary, Watson, you can see everything. You fail however, to reason from what you see. You are too timid in drawing your inferences.’

*Sherlock Holmes by Sir Arthur Conan Doyle*

‘I never made one of my discoveries through the process of rational thinking.’

*Albert Einstein*

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R-DNA

# Chapter 1

## Introduction

Rapid DNA analysis has been standard procedure for years in the well-known series 'CSI' to identify perpetrators within hours. Although this series is clearly fiction, it is possible that 'CSI' predicts the future forensic investigation process. This thesis describes how a mobile Rapid DNA analysis device can be used to act as a potential effective tool in modern day law enforcement. In 2010 the FBI established a Program *Rapid DNA analysis* for the introduction of rapid and mobile DNA technologies for use by law enforcement (1). As it can be expected that mobile DNA technologies will cause a paradigm shift in the role of forensic institutes and the tasks of professionals in the Criminal Justice System (CJS) we have investigated how mobile Rapid DNA technologies can be used efficiently and successfully in the CJS in the Netherlands. Key figures on the contribution of DNA to the identification of suspects and on the actual success rate of the DNA profiling process in analysing biological traces form a wide range of items illustrate the potential benefit of implementing mobile and Rapid DNA technologies in the Dutch CJS. We show how the possibility to deploy Rapid DNA analysis at the crime scene affects the decision-making processes of Scene of Crime Officers (SoCOs) regarding the selection of biological traces for subsequent DNA analysis. For that reason, we developed a decision model for the use of mobile Rapid DNA technologies by SoCOs. We also point out the need to establish a legal environment conducive to the harmonious introduction of mobile Rapid DNA technologies at the crime scene.

## 1.1 DNA as Investigative Tool

DNA analysis for forensic purposes became important more than three decades ago when Sir Alec Jeffreys discovered individual specific DNA patterns leading to the well-known forensic DNA fingerprint (2, 3). The use of DNA analysis for intelligence purposes and as scientific evidence in criminal cases has grown tremendously ever since. A lot of research effort has been devoted to exploring the full potential of DNA technology to identify perpetrators, solve crimes, protect the innocent and to identify missing persons (4). Part of this research has concentrated on the analysis of samples containing low levels of DNA. This technology enables the forensic community to obtain informative DNA typing data from a broad spectrum of crime scene samples (5, 6).

## 1.2 Rapid DNA

Over the last years many studies have been performed to create fully integrated DNA analysis systems with the purpose of speeding up the current DNA analysis process (7-13). This has led to a Rapid DNA Program Office established by the FBI in 2010, to facilitate the development and integration of Rapid DNA technology for use by law

enforcement. This programme was set up to create a way to rapidly analyse reference samples of a suspect while the arrestee is still in police custody and to compare his/her profile with the profiles in the Combined DNA Index System (CODIS) database of unsolved crimes (1).
In 2011, the first promising mobile Rapid DNA technologies were launched that are able to perform Short Tandem Repeat (STR) analysis of reference samples (mouth swabs), human tissue samples, and objects with low DNA copy numbers, allowing for the potential analysis of crime scene samples (14). Given these developments, the time was right to set up a large project in the Netherlands with the goal to examine the impact of "bringing science to the crime scene", with the aim to support the intelligence process in identifying perpetrators (15). The research into mobile and Rapid DNA technologies is part of this project. The project started in August 2012 when Rapid DNA analysis options came into view in the field of forensic science (16). The goal of these new technologies was to create a Rapid DNA analysis system that can be operated by the SoCOs directly at the crime scene and to obtain DNA analysis results within two hours. Some of these developments were discontinued (MiDAS (8)), some took a long time to progress (MinIon (17)), some are still progressing (DNAscan (18), Portable DNA analyzer (19)) and a few actually resulted in working mobile Rapid DNA systems for forensic use (RapidHIT 200 (20), ParaDNA (21)). At the start of this research project it became evident that mobile Rapid DNA technologies are finding their way in the forensic world and without doubt will have an impact on future criminal investigative practices.

## 1.3 Rapid DNA at the Crime Scene – The Research Question

To assure that criminal investigations will benefit from the full potential of mobile Rapid DNA technology it is important to understand how to use this technology at the crime scene. This raises the following research question:

*"What is the impact of implementing mobile Rapid DNA technologies at the crime scene to identify a perpetrator and how can we optimally regulate the process of analysing and obtaining Rapid DNA profiling results to ensure acceptance within the criminal justice system?"*

To answer this question, it should be realised that implementing Rapid DNA technology will lead to a technology-driven change in the complex field of the CJS. On the one hand, accelerating the investigative process can be extremely valuable to rapidly identify perpetrators and solve crimes. On the other hand, it is of the utmost importance to prevent any miscarriage of justice due to the wrongful analysis and interpretation of DNA evidence. Many parties are involved in the process of convicting or acquitting a

suspect in a criminal investigation; these are mainly the police, the laboratory, the prosecution, the defence, the court of law, the Ministry of Justice and even the public (Figure 1). All these parties fulfil different roles and represent different values in the criminal justice chain. It is therefore important to realise that the integration of a mobile Rapid DNA analysis option at the crime scene will have an impact on current processes and/or the beliefs of these parties.

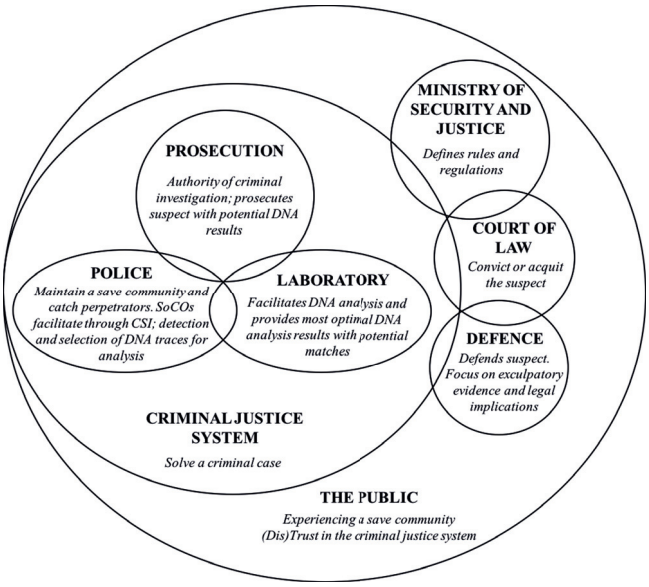



**Figure 1.** DNA evidence in the criminal justice chain

To summarise the current forensic DNA process in the Netherlands: it starts with a crime scene where SoCOs perform their investigation and collect DNA traces. After a selection process the DNA trace(s) are upon request of the Public Prosecutor sent to the laboratory for analysis. The outcome of the investigation is submitted to the prosecutor and the police, after which a suspect may be apprehended and the DNA match might serve as evidence in the court of law. Figure 1 shows the relation between the different parties in the criminal justice chain when considering DNA evidence. The prosecution is the authority of the criminal investigation and safeguards the legal process of the CSI and analysis procedures to finally prosecute a suspect. Both the police and the prosecution are mainly focused on rapidly identifying a suspect during the intelligence phase of the investigation and finding evidence to build the case in the evidence phase of the investigation. SoCOs facilitate this process through performing crime scene investigation (CSI) to detect, collect and select traces for DNA analysis. The laboratory facilitates the process of DNA analysis and is focused on obtaining the best DNA analysis results leading to potential matches. The defence is mainly focused on acquitting the suspect, potentially through exculpatory evidence, discovering implications of misjustice or 'flaws' in the process and chain of evidence. The court of law is the final decision-maker to convict or acquit. The Ministry of Justice proposes legislation for the rules and regulations under which the CJS and the criminal trial need to operate. And finally, the public either trusts or distrusts the CJS, based on the perceived integrity of the CJS and safety of the community.

## 1.4 Sub-research Questions

Once the Rapid DNA technology becomes available the current process of collecting, selecting and using the DNA evidence will change and the parties involved may find themselves in a conflict of interests. The police are focused on rapidly apprehending a suspect rather than using the most sensitive and optimal, but often time-consuming, DNA analysis technique used by the laboratory. This underlines the necessity to map the road ahead in the forensic DNA analysis process once the Rapid DNA technology is ready to be integrated. In this respect the following sub-questions were formulated:

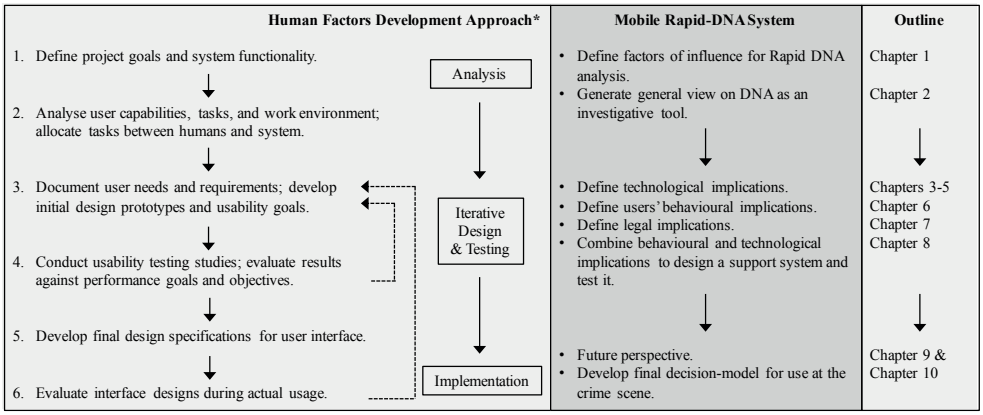
1. What is the current DNA success story in terms of identifying a suspect?
2. What are the DNA success rates for various items or traces?
3. Can this knowledge on DNA success rates assist the Rapid DNA analysis procedure?
4. How will SoCOs operate when Rapid DNA analysis is introduced?
5. How can the Rapid DNA technology be used within the current legal situation?
6. How can we optimally regulate the decision-making process when Rapid DNA is used at the crime scene?
7. What is the future perspective of forensic investigations when Rapid DNA analysis at the crime scene becomes feasible?

## 1.5 Research Project

The research questions above reveal that a technology-driven study will affect all parties within the CJS. There is a need to understand 1) the technological implications of the Rapid DNA analysis system and 2) the behavioural implications at the crime scene when deciding to use Rapid DNA analysis. The challenge in this research is to link technological science, behavioural science and juridical science to obtain a better understanding of the procedural and contextual aspects of applying the Rapid DNA technology. This knowledge can be used to understand the decision-making process and to make future recommendations for the DNA analysis procedures. To optimally approach this topic, the *Human Factors Development Approach* (Figure 2, (22, 23)) was used as an example to systematically combine the interaction between humans, technology and information. This enables the CJS to better assess the future use of the given technology in practice for decision-making and policy recommendations. The Human Factors Development Approach consists of three phases:

1. The *Analysis phase*, in which the objectives and factors for Rapid DNA analysis are analysed. To paint a broad picture of current and future processes we will take behaviour, capabilities, tasks and the work environment into account.
2. The *Iterative Design & Testing phase* uses the information from the analysis phase to define users' implications of Rapid DNA analysis and to collect data through human performance observations. In this second phase the requirements for a potential design are formulated and tested with technology users.
3. The *Implementation phase* serves to improve the design for operational use and to test it in actual cases before implementation of the mobile Rapid DNA analysis (22, 23).

This study focuses on the first two phases to formulate a final design for a possible future implementation of Rapid DNA technologies. For the first phase, knowledge regarding the following factors is essential: the current status quo of Rapid DNA analysis, DNA success rates, crime scene practices, decision-making and human factors at the crime scene, the effect of implementing new technologies, Rapid DNA and the law, and rational decision-making. The second phase focuses on Rapid DNA analysis at the crime scene and seeks to develop, test, analyse and document the requirements and objectives needed for working with this new technology. The dissertation ends with summarising and reflecting on the studies performed and considering the knowledge obtained to answer the main research question. In addition, a final design for implementing Rapid DNA technologies at the crime scene is discussed, with a vision on the way forward in crime scene investigation.



(*Salvemini 1999, 2015 (22, 23))

**Figure 2.** Human Factors Development Approach used to Outline this Research Towards Integrating Mobile Rapid DNA Systems at the Crime Scene for the use of Scene of Crime Officers.

## 1.6 Relevant Factors in Rapid DNA Analysis

### 1.6.1 Status Quo Rapid DNA Analysis

Speeding up crime scene investigations and solving backlogs has since long been a point of discussion in forensics (4, 24-27). In 2002 the UK started implementing what they call 'DNA fast-tracking' which is considered an initiative to *"reduce the time taken to capture, analyse and match DNA against the national DNA database and the subsequent police response to hits"* (25). DNA databases have been shown to have great potential for the criminal investigation, particularly at case level. Matching traces with the DNA database has also proved valuable for broader strategic criminological research to identify unknown offenders, serial offenders and/or co-offenders (28, 29). DNA fast-tracking seems especially useful to speed up the process of identifying a suspect through DNA when there are no direct leads in a criminal case. In the Netherlands such a DNA fast-tracking option is the product called 'DNA-6 hours' at the Netherlands Forensic Institute (NFI). This can be used by the police in specific cases to rapidly analyse DNA traces for indicative purposes (30, 31). The current DNA analysis process from crime scene to laboratory is shown in Figure 3 and the turnaround time of this process depends strongly on the time between the crime scene investigation and start of the analysis procedure at the laboratory. The fastest option for standard analysis of a DNA sample at the laboratory is roughly 9 to 12 hours, and it consists of several process steps as shown in Figure 3 (32).

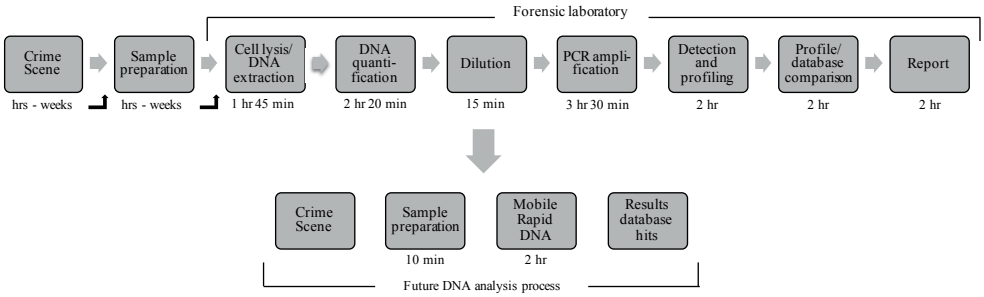



**Figure 3.** Current and Future DNA Analysis Process

Studies have shown that reducing the turnaround time could result in earlier identification, which in turn might quicken offenders' apprehension and incarceration rates and therefore a more substantial impact on crime solving is expected (25, 27, 28). All together this suggests that a fast throughput of forensic DNA samples for analysis is crucial for criminal investigations.

Currently, there are technologies that make it possible to process DNA samples immediately at the crime scene. The objective of such a mobile Rapid DNA analysis

system is to process a DNA sample at the scene, in order to generate intelligence concerning the source of the sample that can be used to identify and capture a suspect within hours, if possible. This possibility could have great value for a criminal investigation. Especially when a suspect is still on the run, the safety of society could be at stake if the suspect is not identified rapidly. By swiftly apprehending the suspect, he or she may still be carrying traces of the crime upon arrest, for instance DNA evidence of the victim or the stolen goods. As a result, a much stronger case could be built, and by taking offenders from the streets more quickly, crime rates could be reduced. This is expressed by Van Asten (2016) (33) *"Any criminal investigation is aided by immediate results as it provides police teams with important information to solve the crime in the important initial hours after its discovery. Providing real-time forensic information can, however, be very valuable as it allows these police teams to direct the investigation, use their scarce resources efficiently and effectively and ultimately solve more crimes."*

The mobile Rapid DNA technology seems to open up the option of establishing immediate results on site and to allow investigators to pursue their criminal investigation more quickly and more effectively. Several manufacturers have created computer type Rapid DNA systems for this purpose that require minimal training to be operated (20, 34-36). It merely requires swabbing a trace and inserting the trace sample in the system and having the DNA analysis carried out at the push of a button. This dissertation does not go into the detail of the internal functions of the Rapid DNA systems, but factors of sensitivity, sample consumption and contamination issues are important to take into account when designing future DNA analysis procedures.

The Rapid DNA technology is a fully automated sample-in answer-out profiling system for STR based human identification (35). These systems integrate all laboratory steps as indicated in Figure 3, including data analysis to generate DNA profiles within 2 hours (37), enabling an effective future DNA analysis process. Although all DNA analysis steps are integrated into this one system, the process could result in less sensitive DNA analysis. For crime scene samples it is essential to realise that the quantity of DNA is often low, as 'touch' DNA samples are frequently collected from the crime scenes. Touch DNA samples usually contain (much) less than 100 picograms of DNA, requiring the most sensitive analysis options such as Low Copy Number (LCN) DNA analysis (32, 38, 39). Additionally, most Rapid DNA systems lack the possibility of securing part of the sample for re-analysis and mobile analysis should therefore be considered destructive. This could impact the use of Rapid DNA analysis and effect future Rapid DNA procedures. The most recent literature shows that Rapid DNA technologies are progressing to analyse DNA samples as low as 50 picograms of DNA when directly pipetted in the cartridge (40), possibly opening up ways for the future analysis of a wide range of trace samples including touch DNA samples.

### 1.6.2 DNA Success Rates

As explained in the previous section, the sensitivity of the Rapid DNA analysis systems is lower than the conventional laboratory techniques. The DNA success rate factor will therefore play a vital role in Rapid DNA analysis procedures. Knowledge of success rates is crucial for future decisions on whether to use Rapid DNA or conventional analysis of crime scene samples. A thorough literature review revealed scarce and incomplete knowledge on the DNA success rates of various traces used in criminal investigations (5, 41-46). So far it is known that DNA success rates of different categories of traces vary, but it is unclear how this knowledge will assist the DNA laboratory or the SoCOs in the triage and selection process of DNA traces from the crime scene. This becomes especially important once rapid analysis of DNA samples at the crime scene becomes reality.

The majority of the studies on DNA success rates were merely on a successful analysis of a certain DNA trace in a case, but did not investigate the nature of DNA typing results obtained in combination with the amount of DNA extracted. In general, these studies ranked DNA success rates in terms of body fluid versus contact/touch traces. Based on these studies it can be concluded that body fluids yield the highest success rates and contact traces the lowest. However, DNA results from various traces, taking into account the nature of the DNA sample, the quality of DNA, the quantity of DNA, the DNA profile and matching results should be combined to obtain the complete story on DNA success rates. This is vital knowledge for the triage decision to analyse traces rapidly on the crime scene or at the laboratory.

### 1.6.3 Crime Scene Practice

SoCOs are often the first responders to investigate the crime scene. They are the ones 'reading' the crime scene in search of forensic evidence to build a case. The core business of the SoCOs is to detect, collect, prioritise and select traces for analysis to help identify suspects and/or to serve as evidence in the criminal trial.

For the detection and collection phase of the crime scene practice, Dutch SoCOs are required to follow the systematic 4-phases model: 1) an initial general examination ('walkthrough') of the crime scene known as the orientation phase; 2) creating a plan of approach; 3) a trace detection and collection phase known as the forensic examination, and 4) a final walkthrough of the crime scene after which preliminary results are formulated (47-49). The 4-phase model is followed by the process of selecting traces and deciding to forward traces for analysis to the laboratory. This process is typically conducted at the police station where scenarios are formulated and all evidence is weighed before traces are send to the laboratory. Finally, the DNA typing results are used in the criminal investigation, either as 'forensic intelligence' to arrest a suspect or serve as 'forensic evidence' in court. Structuring the crime scene practice process in this way serves to minimise the possibility of overlooking important traces and to collect

necessary information to build the case. This process is in accordance with international guidelines for crime scene procedures (50-53). Based on these guidelines and knowledge about common procedures, the complete process from crime scene to DNA profile with the accountable professionals can be summarised as followed:

1. Securing and protecting the crime scene (and its traces)- *police officer*
2. Preliminary non-intrusive orientation on the crime scene including a walkthrough, observation and documentation - *scene of crime officer*
3. Plan of approach including initial views on crime scenarios (hypotheses) of what could have happened to assist in detecting and collecting traces - *scene of crime officer*
4. Detection, collection and documentation of the localised physical evidence at the crime scene - *scene of crime officer*
5. Rounding up the crime scene investigation with a final walkthrough, gathering all evidence and information to be taken to the police station and securing the crime scene - *scene of crime officer*
6. Detailed formulation and documentation of crime scenarios to assist the process of trace prioritisation, selection and decision for further (scientific) analysis - *scene of crime officers (sometimes in cooperation with tactical officers, forensic experts and/or prosecutors)*
7. (Scientific) analysis of the selected traces at the forensic laboratory (i.e. DNA analysis) or police station (i.e. fingerprint analysis) - *forensic analysts*
8. Interpretation of results from the analysed traces - *forensic experts*

For the purpose of Rapid DNA analysis at the crime scene, the current 4-phase model used in the Netherlands for crime scene practice will be incomplete, as the selection and decision process to analyse a trace also must be made at the crime scene. This will probably result in more complex guidelines for SoCOs conducting a crime scene investigation. To detect and collect traces, SoCOs need to recognise the nature of the detected trace evidence and need to recognise and understand the link of a trace with the crime. Once Rapid DNA analysis becomes operational, SoCOs will also need to consider the immediate analysis of the trace at the scene, by quickly assessing the trace's suitability for analysis and the usefulness of the results in the given context (54). A new model integrating all steps of the process from crime scene to result, as described above, is essential for future Rapid DNA analysis processes, to maintain a secure and consistent chain of custody.

### 1.6.4 Decision-making and Human Factors

A crime scene investigation is an observer-based process and often performed by just one or a few SoCOs. The selection process of traces at the crime scene is an issue of

subjectivity. It all depends on whether the SoCO detects and recognizes the trace to start with. This indicates that a crime scene investigation is more than a scientific process: *"forensic evidence is not simply 'found' at a crime scene; it is socially constructed"* (55). Making decisions at the crime scene is therefore not only influenced by technical possibilities but also by human factors and capabilities, and the process is therefore prone to errors. To make correct decisions, an expert needs knowledge, skills, good judgment and experience to optimally evaluate and interpret information; but *"being an expert does not necessarily mean error-free performance; in fact, almost every specialist domain is subject to error" (56)*. Nonetheless, at some point decisions have to be made and decisions often have to be made under time pressure, without knowing the ground truth of the crime.

Zero bias is not possible as long as humans investigate crime scenes (57). Therefore, the influence of human factors on decision-making can never be fully ruled out as long as crime scene investigation is a human and thus an observer-based process. Once mobile Rapid DNA analysis becomes operable, it is likely to have an effect on the focus of the SoCOs. This could potentially cause the investigation to focus on finding and analysing alleged perpetrator related traces[1], and as a result overlooking other crime related traces (48).

It is important to examine these issues within an empirical and experimentally-based real world setting (56, 58), and acknowledge the possible impact of human factors on the decision-making process for DNA trace analysis at the crime scene. Understanding these processes is crucial to create better procedures and training, to achieve an optimal use of the rapid technology, and to improve decision quality (59).

### 1.6.5 Decision-making and Implementation of Technology

The implementation of new technologies is likely to influence the decision-making process. When investigating a crime scene, standard procedures have become embedded and, in combination with experience, have resulted in a certain 'standard' on how to do things (60). The interaction between human action, cognitive factors and the use of technology can challenge this standard (61, 62).

The assumption is that a rapid and efficient flow of information through the implementation of new technologies will help improve police work (63, 64). However, there is little literature on the impact of implementing new technologies on the effectiveness and efficiency of a criminal investigation (63, 65-68). Currently, the police often integrates technologies without examining the impact on the outcomes and procedures (64). Technological advances do not always produce straightforward improvements. The effects are complex and sometimes contradictory, and can even

[1] We use the term 'perpetrator relatedness' throughout this thesis to indicate the potential connection of the perpetrator and the trace.

reduce police effectiveness (64, 66). Without careful research on the actual impact of new technologies, they may not bring the expected and desired outcomes (64).
The introduction of Rapid DNA technology is expected to enhance forensic intelligence to identify an offender. To avoid problems in the implementation of the Rapid DNA technology, it is imperative for researchers and practitioners to work together to analyse opportunities and consequences before implementation. It is therefore necessary to analyse current routines at a crime scene and to investigate how current crime scene practice may or should change when Rapid DNA technologies are introduced. For this purpose, empirical 'real world' experiments need to be designed to test current and future crime scene practice before moving towards implementation.

### 1.6.6 Rapid DNA and the Law

Before implementing Rapid DNA analysis in the CJS, it is important that the technology and the process are recognised by the legislators.
DNA testing as part of the criminal investigation is embedded in the Dutch Code of Criminal Procedure (Dutch: *Wetboek van Strafvordering*) and the DNA (Criminal Cases) Tests Decree. In the Netherlands the public prosecutor is the authority to order a DNA test, which is defined as *the analysis of cellular material with the sole purpose of comparing DNA profiles*. Once the public prosecutor authorises the DNA test of a trace, the trace will be submitted to a forensic laboratory. The current Dutch law stipulates that this DNA analysis must be performed by a designated expert, who is affiliated with a laboratory that has been accredited for this purpose. In addition, the law states that the expert must draw up a report detailing the results of the performed DNA test.
This implies that the use of Rapid DNA technology at the crime scene is bound by law and cannot simply be integrated as such. Therefore, an analysis of the legislative issues relating to current DNA analysis and the future possibilities of Rapid DNA analysis at the crime scene is essential.

### 1.6.7 Rational Decision Theory

Implementing a new and Rapid DNA technology will not only be a challenge to legislators, but it will also impact the current crime scene practice and decision-making process. The decision to immediately analyse traces can be a risk or an opportunity because the outcome of the analysis can have consequences for the rest of the investigative process (69). Not only can Rapid DNA results potentially lead to tunnel vision when traces are not perpetrator related and innocent people are rapidly identified as suspects, but also if the traces are perpetrator related Rapid DNA analysis can entail risks. On the one hand, performing a Rapid DNA analysis may result in rapid intelligence information; but, on the other hand, it can also lead to the loss of the sample if the amount of DNA in the sample was apparently too low for rapid analysis. To weigh these risks and opportunities, it is important to set a way on how to make decisions for

using the Rapid DNA analysis or not. Rational Decision Theory (RDT) could offer a solution to this issue through acknowledging all possible outcomes and explicitly evaluating the consequences of all these possibilities (70, 71). This can be modelled in a Decision Support System (DSS) that can assist SoCOs in dealing with the Rapid DNA analysis option.
In this case SoCOs are uncertain about what will happen when deciding to analyse a trace with the Rapid DNA technology because the true nature of the trace is unknown. RDT offers a simple way of quantifying the relative consequences of the possible outcomes into a decision threshold that may assist in making decisions on the use of the Rapid DNA analysis. We expect SoCOs to deal with uncertainties, through the use of a DSS, to make evidence-based decisions on the potential fitness of crime scene samples for rapid DNA analysis. The decision depends on the case and trace characteristics, and the Rapid DNA success rate of the trace in question.
Designing a DSS for Rapid DNA analysis based on RDT can help to develop a transparent and knowledge-based decision process, and using this system can result in a better-motivated reasoning, which benefits the thoughtfulness and the transparency of this process.

## 1.7 Outline and Contents of the Thesis

To study the impact of a Rapid DNA technology at the crime scene eight different studies were conducted. These studies are outlined in Figure 2 and further explained in the next sub paragraphs.

*DNA as an investigative tool*
This study gives a general view on DNA testing as an investigative tool. For this purpose, it is essential to analyse the role DNA can play in the intelligence process to identify a suspect. Therefore, three key features were monitored in the DNA typing process of DNA traces from crime scene to DNA report: 1) the quality of the profile; 2) the turnaround time of the various steps in this chain; and 3) the number of cold hits. By analysing these features, an initial view and understanding can be generated on the future influence of Rapid DNA analysis to speed up the criminal investigative process. For this, the study on *'DNA in the criminal justice system: the DNA success story in perspective'* was set up and carried out as described in Chapter 2.

*Technological implications*
Rapid DNA technologies are less sensitive than traditional laboratory analysis and the inserted sample should be considered as consumed. Consequently, DNA success rates of several DNA evidence samples are essential to obtain solid knowledge on DNA success probabilities. This will permit the development of a design that integrates this

evidence-based knowledge on DNA success rates, to benefit the current forensic crime scene procedure and to optimise the current laboratory DNA analysis process. Therefore, a predictive analysis was performed and discussed in Chapter 3 in the study *'DNA by the numbers - locations of usable DNA based on 24,466 crime samples'*. This predictive analysis led to the study *'Knowledge on DNA success rates to optimise the DNA analysis process: from crime scene to laboratory'*, aimed at gaining scientific evidence-based knowledge on DNA success rates for both laboratory use and for SoCO use in their crime scene procedures, as discussed in Chapter 4. These studies opened the way to further analyse the impact of less sensitive Rapid DNA technologies on various crime scene DNA samples and to design an initial Rapid DNA analysis triaging and selection process as discussed in Chapter 5: *'Objective data on DNA success rates can aid the selection process of crime samples for analysis by rapid mobile DNA technologies'*

*Behavioural implications*

Here we have defined behavioural implications for the collection, selection and analysis process of DNA traces. By setting up a 'real-life' study, the effect of having a Rapid DNA analysis option on the SoCOs crime scene practice and decision-making process could be studied. The purpose of this study was to gain insight into the focus of the SoCO during the crime scene investigation, the SoCO's awareness of DNA success rates before making decisions, the type of DNA traces collected and analysed, and the effect on making decisions if Rapid DNA analysis is possible. Subsequently, it is important to learn whether the expected DNA success rates as rated by SoCOs match the actual DNA success rates. Together these results can be used to set out the further features necessary to improve the Rapid DNA selection process and to design a decision-making process for Rapid DNA analysis. For this purpose, a mock crime scene of a violent home robbery was created where all participating SoCOs performed the same controlled CSI either with or without a Rapid DNA analysis opportunity. This study on *'Rapid DNA analysis at a mock crime scene - The impact on collecting and analysing DNA traces'* is discussed further in Chapter 6.

*Legal implications*

The legislative implications are explored for implementing Rapid DNA analysis at the crime scene. The current DNA analysis procedure is strictly embedded with safeguards in the Dutch Criminal Procedure Code. It is therefore important to analyse the possibilities and impossibilities of the future use of Rapid DNA technologies by SoCOs under the current law; this matter is addressed in Chapter 7, *'Mobile DNA technologies in crime scene investigation: the legal framework'*.

*Decision Support System (DSS)*
In this study we combined the technological, behavioural and legal implications to design a DSS for the use of Rapid DNA analysis and to test it with SoCOs. In this DSS, the technological implications of the Rapid DNA success probabilities are combined with the behavioural implications of the decision to analyse a trace rapidly, and to design a way for Rapid DNA analysis decisions to be thoughtful and transparent, and to be accepted by the court of law. Therefore, in Chapter 8 *'Decision support for using mobile Rapid DNA analysis at the crime scene',* the DSS is designed and tested to evaluate performance when mobile Rapid DNA analysis is possible. It is further analysed whether this DSS meets the requirements and objectives for the future handling of DNA crime scene samples by SoCOs.

*Future perspective*
In the last part of this research we offer the professionals of the CJS with a realistic view on the future of forensics and anticipate the idea of bringing modern technology to the crime scene. The goal is particularly to create an integrated forensic platform and to use technology to connect the laboratory to the crime scene, requiring both the forensic experts and the police to work together on developing technological and user interfaces. This study on *'The interface between forensic science and technology: how technology could cause a paradigm sift in the role of forensic institutes in the criminal justice system'*, as discussed in Chapter 9*,* supports the final phase of implementation in this research. Through reflecting on all studies performed as part of this thesis and considering the specifications for optimal use within the CJS, the final 'Rapid DNA analysis decision-model' is presented in Chapter 10 Reflection and Future Perspective.

## 1.8 References


1. FBI. Rapid DNA analysis. Retrieved from: https://www.fbi.gov/services/laboratory/biometric-analysis/codis/rapid-dna-analysis
2. Jeffreys AJ, Wilson V, Thein SL. Hypervariable'minisatellite' regions in human DNA. *Nature*, 1985;314(6006):67-73.
3. Gill P, Jeffreys AJ, Werrett DJ. Forensic application of DNA'fingerprints'. *Nature*, 1985;318(6046):577-579.
4. National Research Council. Strengthening forensic science in the United States: a path forward: National Academies Press; 2009.
5. Dufva C, Nilsson A. Success rate of LT DNA analyses in casework. *Forensic Science International: Genetics*. 2011;3(1):e271-e272.
6. Kloosterman AD, Kersbergen P. Efficacy and limits of genotyping low copy number (LCN) DNA samples by multiplex PCR of STR loci. *Journal de la Société de Biologie*, 2002;197(4):351-359.
7. Bruijns B, van Asten A, Tiggelaar R, Gardeniers H. Microfluidic devices for forensic DNA analysis: A review. *Biosensors*, 2016;6(3):41.
8. Hopwood AJ, Hurth C, Yang J, Cai Z, Moran N, Lee-Edghill JG, et al. Integrated microfluidic system for rapid forensic DNA analysis: sample collection to DNA profile. *Analytical chemistry*, 2010;82(16):6991-6999.
9. Horsman KM, Bienvenue JM, Blasier KR, Landers JP. Forensic DNA analysis on microfluidic devices: a review. *Journal of Forensic Sciences*, 2007;52(4):784-799.

10. Liu P, Scherer JR, Greenspoon SA, Chiesl TN, Mathies RA. Integrated sample cleanup and capillary array electrophoresis microchip for forensic short tandem repeat analysis. Forensic science international: *Genetics*, 2011;5(5):484-492.
11. Scott DJ, Trost P, Albert D, Bienvenue JM, James P. A multi-channel microdevice for PCR amplification and electrophoretic separation of DNA. Retrieved from: https://www.promega.co.uk/-/media/files/resources/conference-proceedings/ishi-23/poster-abstracts/42-poster.pdf.
12. Shaw KJ, Joyce DA, Docker PT, Dyer CE, Greenway GM, Greenman J, et al. Development of a real-world direct interface for integrated DNA extraction and amplification in a microfluidic device. *Lab on a Chip*, 2011;11(3):443-448.
13. Yobas L, Cheow LF, Tang K-C, Yong S-E, Ong EK-Z, Wong L, et al. A self-contained fully-enclosed microfluidic cartridge for lab on a chip. *Biomedical microdevices*, 2009;11(6):1279.
14. IntegenX. RapidHIT 200. Retrieved from: https://integenx.com/tag/news-release/page/3/
15. Poot de CJ. Beter opsporen met het lab op zak http://www.sia-projecten.nl/projectenbank/project/beter-opsporen-met-het-lab-op-zak2012
16. Kloosterman AD, McKeown B, Elliott K, Gardeniers H, Bruijns B, Mapes A. Mobile DNA Technologies, Workshop held at the EAFS 2012 Conference August 22nd 2012.
17. Zaaijer S, Gordon A, Piccone R, Speyer D, Erlich Y. Democratizing DNA Fingerprinting. *bioRxiv*, 2016:061556.
18. GE Healthcare Life Sciences DNAscan. Retrieved from: http://www.gelifesciences.com/webapp/wcs/stores/servlet/catalog-/en/GELifeSciences-nl/products/AlternativeProductStructure_22756/
19. NEC. Portable DNA analyzer. Retrieved from: http://cl.nec.com/es_CL/es/pdf/catalogue.pdf
20. Holland M, Wendt F. Evaluation of the RapidHIT™ 200, an automated human identification system for STR analysis of single source samples. *Forensic Science International: Genetics*, 2015;14:76-85.
21. Blackman S, Dawnay N, Ball G, Stafford-Allen B, Tribble N, Rendell P, et al. Developmental validation of the ParaDNA® Intelligence System—A novel approach to DNA profiling. *Forensic Science International: Genetics*, 2015;17:137-148.
22. Salvemini AV. Challenges for user-interface designers of telemedicine systems. *Telemedicine Journal*, 1999;5(2):163-168.
23. Salvemini AV, Piza EL, Carter JG, Grommon EL, Merritt N. Integrating human factors engineering and information processing approaches to facilitate evaluations in criminal justice technology research. *Evaluation review*, 2015;39(3):308-338.
24. Zedlewski E, Murphy MB. DNA analysis for 'minor'crimes: a major benefit for law enforcement. *NIJ Journal*. 2006;253:2-5.
25. Webb B, Smith C, Brock A, Townsley M. DNA fast tracking. In: Smith MJ, Tilley N *Crime science: New approaches to preventing and detecting crime*. New York, NY: Routledge; 2012.
26. Nelson M, Chase R, DePalma L. Making Sense of DNA Backlogs, 2012—Myths vs. Reality. National Institute of Justice, Office of Justice Programs, US Department of Justice. 2013. Retrieved from: https://www.ncjrs.gov/pdffiles1/nij/243347.pdf.
27. Smith MJ, Tilley N. *Crime science: New approaches to preventing and detecting crime*. New York, NY: Routledge; 2012.
28. Asplen CH. Application of DNA Technology in England and Wales United Kingdom. 2003. Retrieved from:: https://www.ncjrs.gov/pdffiles1/nij/grants/203971.pdf.
29. Moor de S, Beken van der T, Daele van S. DNA Databases as Alternative Data Sources for Criminological Research. *European Journal on Criminal Policy and Research*, 2016:1-18.
30. Nederlands Forensisch Instituut. DNA-6 uur. Retrieved from: https://mijnnfi.nl/pdc/biologisch/dna-haar-vingersporen-bloed/dna-6-uur.html.
31. Verheij S, Harteveld J, Sijen T. A protocol for direct and rapid multiplex PCR amplification on forensically relevant samples. *Forensic Science International: Genetics,* 2012;6(2):167-175.
32. Mapes AA. The expectations within the criminal justice system on the use of mobile DNA-technologies at the crime scene. 2012. Retrieved from: http://dareuvanl/cgi/arno/showcgi?fid=455835.
33. Asten van AC. On the added value of forensic science and grand innovation challenges for the forensic community. *Science & justice,* 2014;54(2):170-179.
34. LaRue BL, Moore A, King JL, Marshall PL, Budowle B. An evaluation of the RapidHIT system for reliably genotyping reference samples. *Forensic Science International: Genetics*, 2014;13:104-111.
35. Jovanovich S, Bogdan G, Belcinski R, Buscaino J, Burgi D, Butts EL, et al. Developmental validation of a fully integrated sample-to-profile rapid human identification system for processing single-source reference buccal samples. *Forensic Science International: Genetics.* 2015;16:181-194.

36. Dawnay N, Stafford-Allen B, Moore D, Blackman S, Rendell P, Hanson EK, et al. Developmental Validation of the ParaDNA® Screening System-A presumptive test for the detection of DNA on forensic evidence items. *Forensic Science International: Genetics*, 2014;11:73-79.
37. Hennessy LK, Mehendale N, Chear K, Jovanovich S, Williams S, Park C, et al. Developmental Validation of the GlobalFiler® Express Kit, a 24-marker STR Assay, on the RapidHIT® System. *Forensic Science International: Genetics*, 2014;13:247-258.
38. Lowe A, Murray C, Whitaker J, Tully G, Gill P. The propensity of individuals to deposit DNA and secondary transfer of low level DNA from individuals to inert surfaces. *Forensic Science International*. 2002;129(1):25-34.
39. Gill P, Whitaker J, Flaxman C, Brown N, Buckleton J. An investigation of the rigor of interpretation rules for STRs derived from less than 100 pg of DNA. *Forensic Science International*, 2000;112(1):17-40.
40. Salceda S, Barican A, Buscaino J, Goldman B, Klevenberg J, Kuhn M, et al. Validation of a rapid DNA process with the RapidHIT® ID system using GlobalFiler® Express chemistry, a platform optimised for decentralized testing environments. *Forensic Science International: Genetics,* 2017;28:21-34.
41. Baechler S. Study of criteria influencing the success rate of DNA swabs in operational conditions: A contribution to an evidence-based approach to crime scene investigation and triage. *Forensic Science International: Genetics,* 2016;20:130-139.
42. Bond JW. Value of DNA evidence in detecting crime. *Journal of forensic sciences*, 2007;52(1):128-136.
43. Bond JW, Hammond C. The value of DNA material recovered from crime scenes. *Journal of forensic sciences,* 2008;53(4):797-801.
44. Castella V, Mangin P. DNA profiling success and relevance of 1739 contact stains from caseworks. *Forensic Science International: Genetics,* 2008;1(1):405-407.
45. Harbison S, Fallow M, Bushell D. An analysis of the success rate of 908 trace DNA samples submitted to the Crime Sample Database Unit in New Zealand. *Australian Journal of Forensic Sciences*, 2008;40(1):49-53.
46. Raymond JJ, van Oorschot RA, Gunn PR, Walsh SJ, Roux C. Trace DNA success rates relating to volume crime offences. *Forensic Science International: Genetics*, 2009;2(1):136-137.
47. Amelsvoort van AG, Groenendal H. *Handleiding optreden plaats delict*. Amsterdam: Reed business bv.; 2013.
48. Gruijter M, Poot CJ, Elffers H. The influence of new technologies on the visual attention of CSIs performing a crime scene investigation. *Journal of forensic sciences*, 2016;61(1):43-51.
49. Van Amelsvoort AG, Groenendal H, Van Manen J. Werkwijze bij het onderzoek op de Plaats Delict (PD) *Justitiële Verkenning*, 2004;30(4):72-83.
50. Gardner C. The impact of police culture on organisational change: The case of police use of DNA. *New Zealand Sociology,* 2015;30(4):78.
51. Gardner RM. *Practical crime scene processing and investigation*. Taylor & Francis Group: CRC Press; 2011.
52. Gardner RM, Bevel T. *Practical crime scene analysis and reconstruction*. Taylor & Francis Group: CRC Press; 2009.
53. Groen W, Berger C. Crime Scene Investigation, archaeology and taphonomy: reconstructing activities at crime scenes. In: Schotsmans E, editor. *Taphonomy of Human Remains: Forensic Analysis of the Dead and the Depositional Environment*. West Sussex: John Wiley & Sons; 2017.
54. Hazard D. The Relevant Physical Trace in Criminal Investigation. Journal of Forensic Science and Medicine. 2016;2(4):208.
55. Julian R, Kelty S, Robertson J. Get it right the first time: critical issues at the crime scene. *Current Issues in Criminal Justice*, 2012;24:25.
56. Dror IE, Charlton D. Why experts make errors. *Journal of Forensic Identification*, 2006;56(4):600.
57. Gigerenzer G, Brighton H. Homo heuristicus: Why biased minds make better inferences. *Topics in Cognitive Science*, 2009;1(1):107-143.
58. Wilson DB, McClure D, Weisburd D. Does forensic DNA help to solve crime? The benefit of sophisticated answers to naive questions. *Journal of Contemporary Criminal Justice*, 2010;26(4):458-169.
59. Dror IE. Perception of risk and the decision to use force. *Policing,* 2007;1(3):265-272.
60. HeijdraG. Corporate behavior as driver for implementing new technology. 2013. Retrieved from: https://ideas.repec.org/p/msm/wpaper/2013-13.html.
61. Marx GT. Rocky Bottoms: techno-fallacies of an age of information. *International Political Sociology*, 2007;1(1):83-110.
62. Dror IE. Cognitive neuroscience in forensic science: understanding and utilizing the human element. *Philosophical Transactions of the Royal Society B,* 2015;370(1674):20140255.

63. Manning PK. Technology's ways: Information technology, crime analysis and the rationalizing of policing. *Criminology and Criminal Justice,* 2001;1(1):83-103.
64. Koper CS, Lum C, Willis JJ. Optimising the use of technology in policing: Results and implications from a multi-site study of the social, organisational, and behavioural aspects of implementing police technologies. *Policing: A Journal of Policy and Practice,* 2014:8(2);*212-221*.
65. Koper CS, Willis JJ, Woods DJ, Hibdon J. Realising the Potential of Technology in Policing - A Multisite Study of the Social, Organisational, and Behavioural Aspects of Implementing Policing Technologies Report 2015. Retrieved from: https://www.researchgate.net/profile/James_Willis/publication/278026001_Realising_the_Potential_of_Technology_in_Policing_A_Mutli-Site_Study_of_the_Social_Organisational_and_Behavioral_Aspects_of_Policing_Technologies/links/5579a7b708ae7521587175c8.pdf.
66. Lum C, Koper CS, Willis J. Understanding the Limits of Technology's Impact on Police Effectiveness. *Police Quarterly*, 2016:1098611116667279.
67. Chan J. Making sense of police reforms. *Theoretical criminology*, 2007;11(3):323-345.
68. Chan JB. The technological game: How information technology is transforming police practice. *Criminology and Criminal Justice*, 2001;1(2):139-159.
69. Hacking I. *An introduction to probability and inductive logic*. Cambridge: Cambridge University Press; 2001.
70. Bonnes J, Vergeer P, Stoel R. Rationele besliskunde in het strafrecht - de sprong van bewijs naar beslissing. *Nederlands Juristenblad*, 2015;90(6):354-416.
71. Parmigiani G, Inoue L. *Decision theory: principles and approaches*. West Sussex: John Wiley & Sons; 2009.


K-DNA

# Chapter 2

## The Role of DNA in Finding an Offender[1]

*The DNA success story as an investigative tool in perspective*

**Abstract**

Based on available statistics, it is not clear how DNA analysis contributes to identifying unknown suspects through a match in the DNA database. To form a picture of the effectiveness of forensic DNA analysis as an investigative tool, all forensic reports of serious crimes (N = 116) and high volume crimes (N = 2791) from the year 2011 at the Kennemerland police district were analysed. DNA profiling results show that for 38% of the traces that were secured for DNA analysis at scenes of serious crimes (N = 384) and for 17% of the traces secured at scenes of high volume crimes (N = 386), no DNA profile could be derived. The turnaround times of DNA traces from the crime scene to DNA report were relatively long: 66 days for serious crimes, and 44 days for high volume crimes. The analysed traces resulted in the identification of an unknown suspect through a match with the Offender DNA database in 3% of serious crime cases and 1% of high volume crime cases. This article argues that the role of DNA for intelligence purposes, to identify a suspect, can be increased by making more use of knowledge regarding the DNA success rates of traces and by further optimising the process of forensic DNA testing in the criminal justice system.

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[1]This chapter is a combination of two comparable complementary articles. One article was published in Dutch as: Mapes A, Poot de C, Kloosterman A. De rol van DNA bij het vinden van een dader. *Tijdschrift voor Criminologie*, 2014:56(3), 29-46. The other article was published as: Mapes AA, Kloosterman AD, & Poot de CJ. DNA in the criminal justice system: the DNA success story in perspective. *Journal of forensic sciences*, 2014:60(4), 851-856.
This study was designed, performed, analysed and published as an article by the first author. The co-authors advised on the set-up of the study and made suggestions and recommendations for the article.

## 2.1 Introduction

The use of DNA analysis in the process of criminal investigation and prosecution has grown tremendously in the past decade. This can be attributed to (amongst other things) the unique characteristics of DNA (1-4). Securing biological trace material at a crime scene can be crucial to the success of the criminal investigation and prosecution. DNA analyses of biological traces can contribute to a reconstruction of events and can play an important role in the prosecution of cases. However, DNA analysis can also be used to identify a person who was not previously a suspect. This happens when the DNA profile derived from secured biological traces is compared to profiles of known persons that are stored in the DNA database. The Dutch DNA database contains the DNA profiles of suspected and sentenced persons and of unidentified traces found at a crime scene. While there has been much attention for the role of DNA in the investigation and prosecution process, and for the status of DNA as evidence, not much is known about the role that DNA plays in the process of identifying an unknown suspect through a match in the DNA database. This study concentrates on the contribution of DNA for the intelligence process to identify unknown suspects, so not on the contribution of DNA analyses to the reconstruction of a crime or to the process of presenting evidence, prosecution and sentencing.

Both in the Netherlands and abroad, the national DNA database is seen as an efficient investigative tool (5-12). At the end of 2012, the Dutch DNA database for criminal cases contained 157,864 DNA profiles of individuals and 52,965 profiles of traces (13). In its annual report of early 2013, the Netherlands Forensic Institute (NFI), which manages the DNA database, reported that 50% of the crime traces that are compared to the profiles contained in the database result in a match with the profile of a person registered in the database (13). According to a study in England and Wales it comes to 59% of the submitted traces (8). However, the fact of a match between one or more traces secured at the crime scene with an individual in the DNA database does not mean necessarily that every trace will lead to identifying a yet unknown suspect.

In a study in 2012 it was attempted to clarify to what extent the DNA database contributes to the identification of unknown suspects, in their evaluation of the DNA Testing Convicted Persons Act (in Dutch: Wet DNA onderzoek bij veroordeelden) (11). They did so based on interviews and analyses of fifteen police files. Based on their analyses, they estimate that half of the cases where a trace turns up a match with a person in the DNA database actually results in the identification of an unknown suspect. However, their study still fails to clarify the exact role of the Dutch DNA database in identifying unknown suspects.

Based on the existing statistics, no answer can be offered to the question how often and in how many cases collected biological traces actually lead to the identification of an unknown suspect through a match in the DNA database, and hence what DNA

contributes to the intelligence phase of a criminal case. It also remains unclear whether and in what way the contribution of the DNA database to the intelligence process could be enhanced. The goal of the current study is to offer a realistic picture of the value of DNA in the intelligence process and of the possible ways of increasing this value.

The extent to which DNA research can play a role in the intelligence process depends on (amongst other things) 1) the quality of the DNA profile from the secured trace, 2) the turnaround time with which trace information can be used in the intelligence process, and 3) the chance that the DNA profile will turn up a match in the DNA database with a yet unknown suspect. This study sets out to examine these factors.

The quality of a trace is relevant to the probability that the trace will yield a suitable DNA profile with which to pursue the criminal investigation. Knowledge regarding the potential value of different types of traces can be used in the process of selecting traces to be submitted for DNA analysis to the laboratory. In theory, selecting the most promising traces will result in more suitable profile results and hence to more traces that are suitable for comparison with the DNA database. This can increase the number of 'hits' in the DNA database, which may lead to a previously unknown suspect – generally referred to as 'cold DNA hits'.

The speed with which a profile can be used in the investigation and serve as intelligence is also important. If the turnaround time for the analysis of biological traces is long, then the obtained profile results may become irrelevant for the intelligence phase, as the suspect may have been identified through other and quicker investigative tools in the meantime.

Finally, the obtained profile must turn up a match with a profile stored in the DNA database. In most studies, the database's contribution to the identification of unknown suspects, or the 'cold DNA hits', is measured from the perspective of individual DNA profiles that are compared with the DNA database. However, in any single case, generally multiple traces are secured and analysed. That is why this approach does not yield an unambiguous insight into the contribution of collected biological trace material to the identification of unknown suspects through a match in the DNA database. In this study we shall examine the contribution of the DNA database to the identification of individual offenders from the perspective of the criminal cases in which this biological trace material was secured and analysed.

By analysing DNA profiling results, turnaround times and database matches, we offer insight into the actual process of DNA based investigations, and into the possible means to improve this process.

In this study, biological traces are followed from the crime scene to the DNA report. The study focuses on police files of serious crimes and high volume crimes in which trace detection was performed by a Scene of Crime Officer (SoCO). In 2012, in one of the former Dutch police districts, the district of Kennemerland, all closed police files

were studied that forensics were involved with in 2011 and for which a SoCO was deployed to the crime scene to collect trace material.

*From crime scene to DNA report*
Biological traces, left at a crime scene, are generally secured by a SoCO from a police forensic department. The SoCO uses an indicative tetra base test to determine whether a blood-like trace actually is blood (14). Other indicative tests, for instance to determine saliva or sperm traces, are usually not performed by the SoCO (15). The secured traces are taken to the police forensic department, and subsequently one or several traces are selected for submission to a forensic laboratory for further analysis, under the authority of a public prosecutor. Most biological traces are submitted to the NFI for further DNA analysis, but traces can also be sent to other accredited forensic labs. At the laboratory, the trace is subjected to a strict protocol for DNA profiling and for the comparison of DNA profiles of traces and individuals stored in the DNA database. At the end of the process, a qualified DNA expert reports the analysis and comparison results.
Traces secured from High Volume Crime cases (HVC cases) follow a different route than traces secured from Serious Crime cases (SC cases). Biological trace material collected at a SC case is usually processed separately, while most of the biological traces collected in an HVC case are submitted to the laboratory for analysis in batches of 28 traces at a time. Only blood and saliva traces are accepted for this HVC route.

## 2.2 Material and Research Method

The selection of closed cases from the Kennemerland district for which a SoCO collected the trace material resulted in 2,907 police files, of which 116 pertained to serious crimes and 2,791 to high volume crimes. A further analysis of these cases was performed based on the forensic reports, including the DNA results that were returned by the forensic laboratory and the (tactical) information about the case that was stored in the police enforcement registration system, *Basisvoorziening Handhaving*, showed that in 243 cases at least one biological trace was secured that was submitted to a forensic laboratory for DNA analysis (see Figure 1). In 67 cases it concerned a serious crime. Specifically, these cases consisted of 29 armed robberies, 8 cases of arson, 8 sexual assaults cases, 5 shooting incidents, 3 stabbing incidents, 3 threats, 3 attempted homicides, 2 thefts with violence, 2 cases involving hard drugs trade, 2 cases of physical abuse, 1 murder and 1 found corpse of an unidentified person. 176 cases involved a high volume crime, specifically: 119 burglaries, 24 investigations into cannabis plantations, 12 attempted burglaries, 15 thefts, 4 cases of vandalism, and 2 cases of arson.

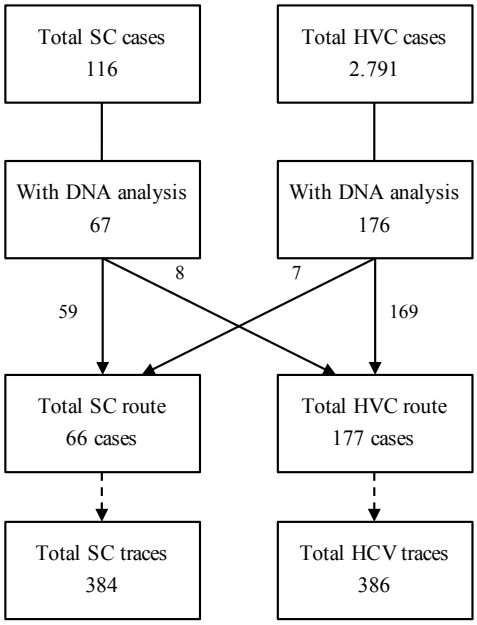



**Figure 1.** Distribution of SC and HVC cases and traces

For all of these 243 cases, the DNA profile results and the turnaround times for each trace that was submitted to a forensic laboratory for further analysis was mapped out.
Next, we examined for each case to what extent the DNA analysis contributed to the identification of a previously unknown suspect through a match in the DNA database.
The number of DNA typing characteristics analysed, generally known as DNA loci, depends on the DNA analysis system that is used. In the Netherlands, DNA profiles consist of 15 loci plus the sex-specific locus Amelogenin. Complete DNA profiles can always be added to and automatically compared with the profiles in the DNA database. It is also possible to compare an incomplete DNA profile (a profile that has not determined all the donor's DNA characteristics of the cellular material) with the DNA database (14, 16). For automated comparison, the DNA profile of the crime stain should contain the typing results of at leas 6 loci (17).
Although HVC cases follow a different route than SC cases, in 7 of the 176 HVC cases it turned out that another biological trace – other than saliva or blood – was significant (Fig. 1). This usually concerns important contact traces. In these cases, the HVC traces followed the SC route. On the other hand, in 8 SC cases traces were secured that followed the HVC route, because the traces were not complex and because the HVC route generally delivers results more quickly (Fig. 1).
To also gain insight into the route followed by traces that were secured in the selected cases, these two routes were analysed separately. In other words, we analysed the results

of the DNA analysis both from the perspective of the cases and from the perspective of the DNA traces from these cases that were submitted to the laboratory.
All in all, 384 DNA samples followed the SC route and 386 DNA samples followed the HVC route. For both routes the DNA profile results and the turnaround times were analysed separately. We furthermore examined per case whether the DNA profiles that met the criteria for comparison with the DNA database yielded a match with profiles in the DNA database and to what extent that match resulted in the identification of a previously unknown suspect.

### 2.2.1 DNA Results of the Individual Traces

*Following the traces in the SC route*
This study only looked at the standard DNA requests. This concerns requests for a DNA analysis that, in case of a suitable DNA profile as a result, can be used to perform a standard profile comparison with DNA profiles in the DNA database. This means that a number of requests for more specialised DNA analysis were not included in our analysis, such as mitochondrial DNA analysis, low copy number DNA analysis or DNA typing of hairs. In the SC route, the results of 384 samples for standard DNA analysis were analysed.
To map out the DNA profile results, all biological traces that were sent to a forensic laboratory for a standard DNA analysis were included in this study. For instance, the investigation at the scene of one of the shooting incidents mentioned above resulted in the collection of six exhibits that potentially contain DNA traces (specifically, three condom wrappings, one box of peppermints, one cartridge case and one sweater) and one sample of blood, found at the crime scene. Further, three reference samples (suspect, witness and victim) were collected. Five exhibits (three condom wrappings, one box of peppermints and one cartridge case), the blood sample and the three reference samples were sent to the laboratory for DNA analysis. At the laboratory, five DNA samples were secured from the five exhibits. The analysis of these samples of the five exhibits and the blood sample resulted in two complete DNA profiles (of which one matched with the victim and one with the witness) and three mixed DNA profiles (of which one matched with the suspect and one with an unknown male). One sample did not yield a DNA profile.
To calculate the turnaround times, the timeframe of each step in the process, from the crime scene to the DNA report, was analysed. For example, the turnaround time in one of the shooting incidents demonstrates a period of six days from the moment that biological traces were secured at the crime scene to the moment of preparing the DNA requests by the SoCO and six days for the authorisation of the DNA requests by the public prosecutor to perform a standard DNA analysis on these traces. Then, seven days passed until the forensic laboratory received the traces and the authorisation for DNA

analysis. The DNA profiling process at the forensic institute had a turnaround time of 68 days. This example shows an overall turnaround time of 87 days from the crime scene to the DNA report.

*Following traces within the HVC route*
Crime scene investigation focused on solving high volume crimes primarily concentrates on finding DNA traces such as cigarette ends, blood and saliva stains. These traces are sampled by the SoCO at the crime scene or in a police research laboratory. To analyse such samples, the forensic laboratory uses an automated DNA analysis system. The samples are analysed in batches of 28, and the results are likewise reported per batch. DNA profiles that meet the criteria will be uploaded to the DNA database and are compared with the profiles of the national DNA database. The entire process of the HVC route is strictly regulated. The turnaround times from securing the evidence at the crime scene until the receipt of the trace batches by the forensic laboratory, and from the receipt of the trace batches until the profiling of the traces and the writing of a report per batch, are also prescribed. The results of the 386 DNA samples that followed the HVC route were analysed in the same way as described above for the SC route.

*DNA results from the perspective of the case*
From the 243 cases (67 SC cases and 176 HVC cases) in which biological traces were sent to a forensic laboratory for analysis, we analysed how often the DNA analysis resulted in a DNA profile and how often these results enabled the successful identification of a suspect. This offers insights into, amongst other things, the number of cases in which an analysed DNA profile leads to a suspect via a match in the DNA database. DNA matches with reference samples of victims or witnesses were not included in this study.

## 2.3 Results

### 2.3.1 Profile Results of DNA Traces

*SC route*
Within the SC route, 384 analysed DNA samples were analysed. The traces that were submitted for DNA analysis mainly concern contact traces (83%). The other traces were from sexual assault (6%), blood (5%), saliva (4%), cigarette ends (0.5%) and nail scrapings (0.5%). Our analyses show that in 38% of all analysed traces (146/384), these DNA analyses did not result in DNA typing information, and that 8% of the DNA analyses (29/384 traces) resulted in a profile that did not meet the criteria to enable comparisons. Looking at these ‘untypable’ traces, it turns out that more than 90% concerns contact traces. See Table 1 for an overview of these results.

**Table 1.** DNA Profile Results of Traces Analysed in the Serious Crime Route

| Profile results SC Traces | Total | Saliva | Contact | Blood | Sexual Related | Cigarette End | Nail Scrapings |
|---|---|---|---|---|---|---|---|
| Complete | 94 | 3 | 58 | 15 | 14 | 2 | 2 |
| Incomplete | 25 | 0 | 22 | – | 3 | – | – |
| Mixed | 79 | 5 | 67 | – | 7 | – | – |
| Incomplete mixed | 11 | 0 | 10 | 1 | – | – | – |
| No profile | 146 | 9 | 132 | 5 | – | – | – |
| Unsuitable | 29 | 0 | 29 | 0 | – | – | – |
| *Total* | *384* | *17* | *318* | *21* | *24* | *2* | *2* |

**Table 2.** DNA Profile Results of Traces Analysed in the HVC Route

| Profile Results HVC traces | Total | Saliva Swab | Cigarette End | Blood Swab |
|---|---|---|---|---|
| Complete | 242 | 59 | 99 | 84 |
| Mixed | 6 | 2 | 3* | 1 |
| No profile | 64 | 55 | 2 | 7 |
| Unsuitable | 74 | 51 | 12 | 11 |
| *Total* | *386* | *167* | *116* | *103* |

**One mixed profile can only be compare manually.*

*HVC route*

A total of 386 DNA traces were analysed within the HVC route. These traces consisted of saliva samples (43%), cigarette ends (30%) and blood samples (27%). Our analyses show that for 17% of the submitted HVC traces (64/386), the DNA analysis did not result in a DNA profile. For 19 % of the submitted HVC traces (74/386) the DNA analysis yielded a profile that did not meet the criteria to enable comparisons. As Table 2 shows, it is mainly saliva samples, not derived from a cigarette end, that often fail to yield a suitable DNA profile for comparison. The chance that cigarette ends and blood samples yield a suitable DNA profile is much higher than the chance that saliva samples, found in other places than on a cigarette end, will yield a suitable DNA profile.

### 2.3.2 Turnaround Times for DNA Traces

*SC route*

In the year 2011, 84 DNA requests pertaining to 66 SC cases were submitted to the forensic laboratory by the Kennemerland police district. Eighteen of these requests concerned follow-up requests pertaining to 13 cases. These follow-up requests were only made later in the investigation process and have therefore been analysed separately in this study, in order to obtain a clear picture of the turnaround times from the crime scene to the DNA report. Table 3 gives an overview of the length of turnaround times from the crime scene to the DNA report.

**Table 3.** Turnaround Times of the Traces from the 66 initial DNA Requests Analysed in the Serious Crime Route, in Days

| Turnaround Time (Days) SC Cases | Crime Scene – DNA Request | DNA Request – Authorisation Public Prosecutor | Authorisation Public Prosecutor – Received at Forensic Lab | Crime Scene – Forensic Lab (Total) | Forensic Lab – DNA Report | Crime Scene – DNA Report (Total) |
|---|---|---|---|---|---|---|
| Median | 28 | 1 | 6 | 41 | 19 | 66 |
| Mean | 43 | 5 | 8 | 53 | 26 | 79 |
| Min | 0 | 0 | 0 | 1 | 1 | 9 |
| Max | 184 | 122 | 61 | 189 | 133 | 201 |

Since the mean length of the turnaround times is strongly influenced by a few number of outliers, we decided to give the median values to allow for meaningful comparisons. For biological traces submitted in the SC route, the full turnaround time from crime scene to DNA report has an 'average' length of 66 days.

*HVC route*

In the HVC route, the analysis and reporting process is strictly regulated and the turnaround times are less affected by the specific features of a case. We also analysed the turnaround times per trace here, and there were some outliers. For this reason, again, we chose to measure median values. The biological traces are stored by the SoCOs for about 24 days before they are sent to the laboratory. The analysis process and releasing the DNA report requires an 'average' period of 21 days. The total turnaround time for the traces analysed in the HVC cases comes to a median period of 44 days, including a DNA analysis process of 21 days. See Table 4 for an overview of these results.

**Table 4.** Turnaround Times of the Traces Analysed in the High Volume Crime route, in Days

| Turnaround Time (Days) HVC Cases | Crime Scene – DNA application | Received by Lab – DNA Report | Crime Scene – DNA Report (Total) |
|---|---|---|---|
| Median | 24 | 21 | 44 |
| Mean | 34 | 21 | 55 |
| Min | 0 | 1 | 21 |
| Max | 278 | 29 | 298 |

*The total turnaround time from the samples of the follow-up request (N = 18) took a median period of 115 days (including a DNA analysis period of 35 days).*

### 2.3.3 DNA Results from the Perspective of the Case

This study also examines how often biological traces lead to the identification of a suspect from the perspective of the case. To this end we analysed the results of DNA profile comparisons between collected traces and the DNA profiles of individuals. This concerns both profile comparisons with previously identified suspects from whom a reference sample is sent to the laboratory, and profile comparisons with individuals whose DNA profiles are contained in the DNA database. For the HVC cases, the

assumption is that the trace submitted for a profile comparison potentially concerns an offender's trace. For SC cases, traces are also compared with the DNA profiles of victims or witnesses. These profile comparisons are not considered in this study.

*Serious crimes*

In 2011, the SoCOs of the Kennemerland police district investigated 116 serious crimes. In 58% of these cases (67/116), DNA trace evidence was secured which were subsequently analysed by the forensic laboratory. Figure 2 presents the results of these DNA analyses.

In 79% of these cases (53/67) there was at least one DNA trace that resulted in DNA typing results. In the remainder of cases, the DNA traces that were secured did not result in DNA typing results. In 21% of these cases (11/53), one or more DNA profiles were obtained (totalling 34 DNA profiles) that resulted in a match with a profile in the DNA database. These DNA database comparisons led to the identification of 12 suspects (in

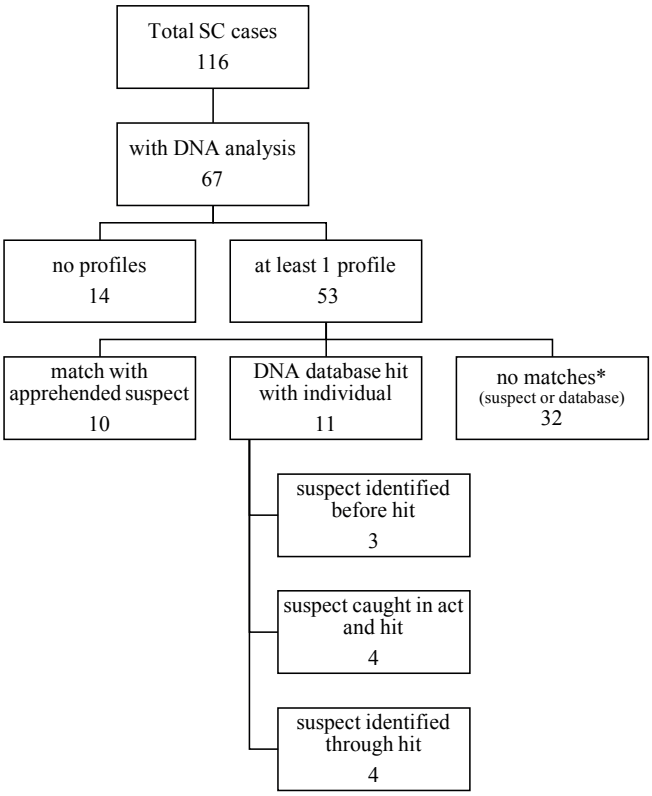



**Figure 2.** DNA Analysis in Serious Crime Cases

one case, the DNA profiles led to a match with 2 suspects). In 4 cases, these DNA database matches turned up a 'cold DNA hit', enabling the identification of a previously unknown suspect. In 3 cases the matching person in the DNA database had already been identified 'tactically' before the database match emerged. In the other 4 cases, the suspect had already been taken into custody before the DNA database match was reported. These last 4 cases involved caught-in-the-act cases, and the profile of the suspect turned out to already be contained in the DNA database for convicted criminals. The 4 cases that yielded a match with the DNA database and where this match actually resulted in the identification of a previously unknown suspect had a turnaround time of 41, 42, 118 and 176 days from the crime scene to the DNA report.

*High volume crimes*

In 2011, the SoCOs of the Kennemerland police district performed forensic investigation in 2,791 cases of high volume crimes. In 6% of these cases (176/2,791),

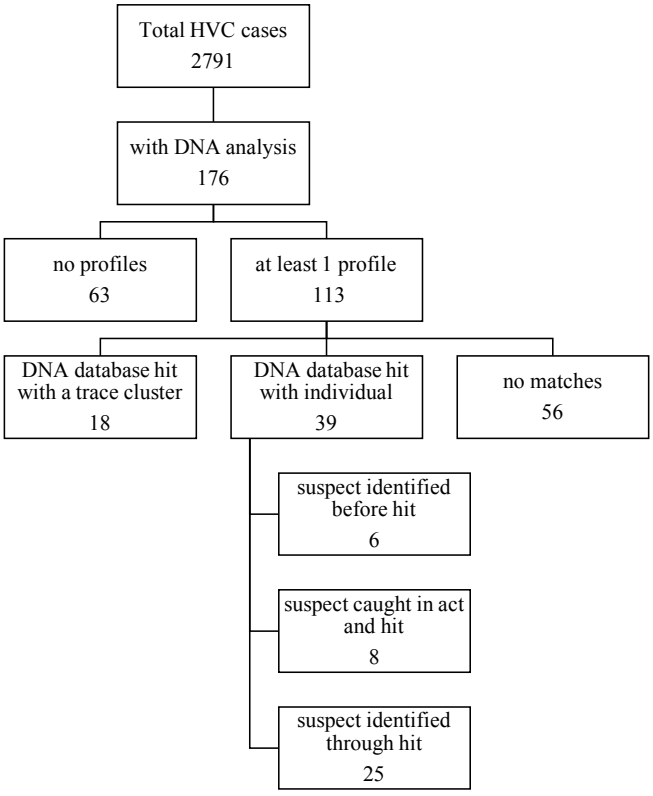



**Figure 3.** DNA Analysis in High Volume Crime Cases

DNA traces were secured that were subsequently analysed by the forensic laboratory. See Figure 3 for the results of these DNA analyses.
In 36% of these HVC cases (63/176), not one secured DNA trace resulted in DNA typing results. In 64% of the cases (113/176), the secured DNA evidence resulted in at least one DNA typing result. In 18 of these cases, at least one trace matched another crime sample in the DNA database not yet associated with an individual; these could result in an identification in the future. In 35% (39/113) of the HVC cases with at least one suitable DNA profile, where 96 DNA profiles were generated in total, a suspect was identified through a match between the trace and an individual in the DNA database. This led to the identification of 37 suspects. In most of the cases with multiple traces there were internal matches, resulting in one match with a suspect in the DNA database. Further, in one case two different DNA profiles were found that resulted in the identification of two suspects. Finally, there was a case in which three different DNA profiles were generated, resulting in the identification of three suspects.
In six cases that resulted in a match with the DNA database, the suspect had already been identified through 'tactical' investigation. In eight cases, the suspect was caught-in-the-act. The remaining 25 cases with matches with the DNA database were actual 'cold DNA hits', so that the suspect could be identified based on this match with the database.

## 2.4 Conclusions and Discussion

Based on this study, we may conclude that many traces ultimately did not result in a DNA profile. Of the traces that followed the SC route, 38% did not yield a DNA profile; of the traces in the HVC route, this applies for 17%. The fact that HVC traces are more likely to yield a DNA profile than SC traces can probably be attributed to the fact that the HVC batches did not include contact traces. The vast majority of traces analysed in the SC route are contact traces (83%). Of these contact traces, 42% failed to yield a DNA profile. In the HVC route, the DNA analysis did not yield a DNA profile for 33% of the saliva traces, 2% of the cigarette ends, and 7% of the blood traces. The chance that a DNA profile can be derived from saliva traces, not taken from a cigarette end, is relatively small. This has also been shown in other studies (18, 19), and is probably due to the fact that saliva traces, like contact traces, are so-called 'invisible traces'. This implies that the SoCO, in order to obtain such traces, must sample places where (saliva) contact is likely to have occurred. However, the SoCO is never certain that (saliva) contact actually occurred in the place sampled.
The foregoing results provide some insight into the likelihood that sampled traces will yield a DNA profile, the DNA success rate. This appears to depend on the type of trace. The SoCO can make better decisions based on DNA success rate knowledge as to which traces should or should not be submitted for further DNA analysis. The most promising

traces can be prioritised and selected for further research, increasing the potential contribution of these traces to the further investigative process. It therefore seems worthwhile having a scientifically evidence-based decision-making model for the selection of DNA traces for analysis by making proper use of DNA typing information. This study is a first step towards developing such a model. This model is currently being elaborated in a research project that works with a greater variety of trace exhibits that went for DNA analysis.

The turnaround times from the crime scene to the reporting of the DNA analysis results to the police team are relatively long. Traces are kept at the police bureau for a long time before being forwarded to a forensic laboratory, and the forensic analysis also takes a relatively long time to complete. A turnaround time of 66 days on average for serious crimes and 44 days for high volume crimes can mean that DNA analysis is less suitable for intelligence purposes, to identify a suspect, than it could be in theory. Although we were unable, in this study, to determine whether any communication with the forensic laboratory on the analysis results occurred in the interim, so before these results were reported in writing, there still appears to be a turnaround time of 41 days before a DNA trace secured at the scene of a serious crime is received by a forensic laboratory for further analysis. An acceleration of the entire DNA analysis process, both at the police and at the forensic laboratory, seems essential to making better use of DNA for the investigative process. Improving the prioritisation process – as discussed in the previous section – is also likely to benefit the turnaround times, as it can accelerate the decision-making on the selection of traces for further analysis.

Relatively few unknown suspects were actually identified through analysis of DNA evidence. The results of our analyses show that a DNA database match was reported for 11 of the 116 serious crimes and for 39 of the 2,791 high volume crimes. For four serious crimes (with turnaround times of 41, 42, 118 and 176 days) and 25 high volume crimes (with an average turnaround time of 48 days), this DNA database match actually resulted in the identification of a yet unknown suspect. The long time that elapses before the results of this investigative tool can be used is striking. For three SC cases and six HVC cases, the report on the DNA database match only came in after the suspect had been identified through other, tactical investigative methods. Although this match proved obsolete in terms of using DNA as a means of identifying an unknown suspect, it could of course serve as evidence in court. These obtained matches are registered in the DNA database, but no distinction is made between actual 'cold DNA hits' that result in the identification of unknown suspects, and hits that actually lead to a match with a suspect identified previously. This also applies for the matches for suspects caught-in-act who were (therefore) already known from the start of the investigation.

The research results show that in cases with a forensic crime scene investigation just 58% of the SC cases (67/116) and in 6% (176/2,791) of the HVC cases DNA traces are secured and analysed. In a U.S. DNA field experiment on property crimes conducted in

2009 (8), a suspect was identified through a DNA database match in 16% of the cases. In 13% of the cases in the "DNA evidence group," a suspect was identified through traditional police work. Compared to the control group where no DNA analyses was performed a suspect was identified in 12.8% of the cases. This study, therefore, implies that the use of DNA can double the probability of identifying a suspect. If we relate these numbers to our study, it can be concluded that although DNA analysis of traces results in a higher probability of identifying a perpetrator, it will have an actual effect in only those cases where biological material from a possible perpetrator has been secured (in this study in 6% of the HVC cases).

The study further shows that overall for 3% of the serious crimes (4/116) and for 1% of the high volume crimes (25/2,791), where a SoCOs performed a forensic investigation at the crime scene, actually led to the identification of a yet unknown suspect through a match in the DNA database. The annual report of the Dutch DNA database concludes that 50 % of the DNA crime traces resulted in a match with a person in the national DNA database (13). This result is based on the DNA profiles of traces that meet the quality criteria required to be included in the DNA database and to be compared with other traces. The annual report furthermore states that the greater the number of DNA profiles stored in a DNA database, the greater the chances of finding a match. Unfortunately, the report offers no information about the number of cases in which the DNA match actually resulted in the identification of a previously unknown suspect. However, It is very important for professionals in the criminal justice chain who need to make choices and who need to deploy their scarce resources efficiently to have insight into these figures. After all, the main goal of the DNA database is to solve criminal cases, not to match profiles.

Similar studies on the application of DNA technology in England and Wales (20) also only report on the profiles that were uploaded in the database. Here, a 39% probability of obtaining a match between a crime scene profile and a profile in their national DNA database (resulting in 21,000 cold hits in 2002–2003) is reported. These 21,000 cold hits actually relate to 998,000 attended crime scenes in that year. This comes down to a success rate of 2.1% when the DNA typing and database process are regarded in case perspective. The number of 2.1% corresponds with the results of our study. It is stated that this "attrition process" (21) actually resulted in 1% searchable DNA profiles from all recorded crimes in that year and demonstrates the real efficiency of the use of DNA to actually identify a suspect in a criminal investigation. It is not clear whether the reported 21,000 hits were actual cold hits or that suspects were already identified through other forensic or investigative disciplines or that there are multiple hits within in the same case.

In this article we have sought to put the success story of the role that DNA currently plays in police investigations into perspective, by considering the results of the DNA analyses from the perspective of an individual case and of an individual trace. This

reveals that the role of DNA in the identification of suspects is not as great as might be expected on theoretical grounds. On the one hand, this can be attributed to the fact that a considerable amount of trace material is analysed that contains too little DNA material to yield a DNA profile, and to the long turnaround times on the other hand. Adjustments to the DNA analysis process but also new techniques could help mitigate both problems in the future, leading to a greater role for DNA analysis in the investigative process. This study offers the SoCOs more knowledge with respect to DNA success rates and creates awareness on the potential of trace DNA in the criminal investigations. This study does not claim that DNA traces cannot meaningfully contribute to the investigative process or to the presentation of evidence. But it does provide the criminal justice system with the true story of DNA analysis.

*Future perspectives of DNA analysis*

DNA success rates, turnaround times, and the use of DNA results during the intelligence phase of the criminal investigation, can potentially be improved in the future by real-time DNA analysis at the crime scene. A tool currently being developed in the Netherlands and internationally is a DNA presumptive test (22-24) with which to determine whether a trace contains sufficient DNA material to yield a DNA profile. As our research shows, presumed biological traces are secured from the crime scene without the SoCOs knowing whether the traces contain sufficient human DNA to enable a DNA profile. It is expected that the future availability of a fast, accurate, and sensitive presumptive DNA test at the crime scene or the police forensic department will lead to a better selection and prioritisation of traces for DNA analysis. It means that less time and energy will be spent on traces that contain too little DNA material or none at all, and will also encourage SoCOs to continue their efforts in localising additional stains that have a more promising potential. It also will relieve the DNA profiling process at the forensic laboratory from putting effort in analysing samples that contain insufficient DNA, thereby reducing the number of traces that undergo unnecessary the complete DNA analysis processes. It is likely that this will increase the role that DNA can play in the identification of an unknown suspect. The available capacity to perform DNA analysis can also be used more effectively.

Several manufacturers in various places are also working on the development of fully integrated instruments for the analysis of DNA samples at the crime scene. These tools will enable SoCOs to generate DNA profiles from traces directly at the crime scene (25-33). Most of these systems are able to derive a DNA profile from a DNA sample within two hours, which can then be compared to profiles stored in a DNA database.

The HVC traces are likely to benefit most from these technologies. HVC traces mainly consist of saliva and blood traces, with high potential for yielding informative DNA profiles. A pre-selection of these traces based on the amount of DNA present in the trace will influence the role that the trace can play in the investigation process. The majority

of traces secured for serious crimes consist of less promising contact traces, however. These traces need to be treated with more care and require more advanced DNA technologies. For the near future, it is therefore expected that the SoCOs at the crime scene will be able to analyse the more promising high-template DNA traces. This will give the forensic laboratories more scope to concentrate on the analysis of minimal and more challenging DNA traces or trace exhibits.

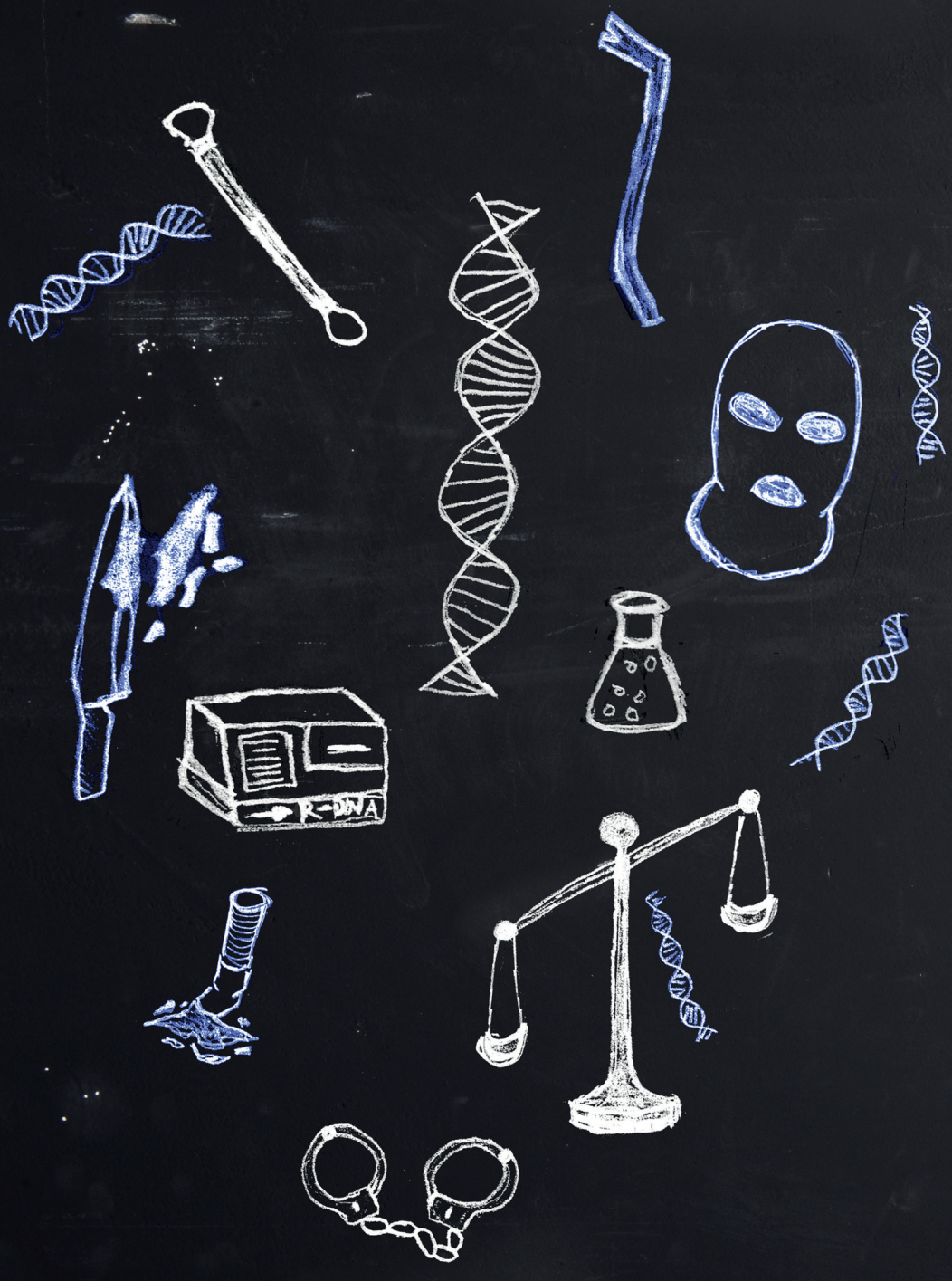
Before altering existing regulations on the integration of new and mobile technologies, it is necessary to get a clear and complete understanding of the present-day existing procedures in the forensic (crime scene) investigation procedures. Knowledge on the DNA success rates of biological traces in their potential to allow for fast mobile analysis or need the expertise from a fully equipped forensic DNA typing laboratory is essential for the justification of a selection process.

Which technologies will be used in the future, how these technologies will influence the investigation process, and what risks these developments pose, remains an open question. That such technologies will be implemented in the future seems clear, however. SoCOs must deal with these new opportunities, and therefore, evidence-based protocols must be established for future crime scene work. Current research is toward creating a safe, correct, and bias-free environment for the integration of a faster DNA analysis process in the criminal justice system. The way forward will inevitably bring more science to the crime scene.

## 2.5 References


1. Broeders A. *Op zoek naar de bron: Over de grondslagen van de criminalistiek en de waardering van het forensisch bewijs.* Alphen aan de Rijn: Kluwer; 2003.
2. Broeders APA. *Ontwikkelingen in de criminalistiek: van vingerspoor tot DNA-profiel-van zekerheid naar waarschijnlijkheid*. Den Haag: Boom Juridische uitgevers; 2005.
3. Kloosterman AD. DNA als gerechtelijk bewijsmateriaal. 2001. Retrieved from: http://bioplein.nl/attachments/File/Humane_Sporen/dna_a_g_b.pdf.
4. Poot de CJ, Kruisbergen EW. *Kringen rond de dader: grootschalig DNA-onderzoek als instrument in de opsporing*. Den Haag: Boom Juridische Uitgevers; 2006.
5. Bieber FR. Turning base hits into earned runs: Improving the effectiveness of forensic DNA data bank programs. *Journal of Law Medicine & Ethics*. 2006;34(2):222-223.
6. Butler JM. *Fundamentals of forensic DNA typing*. Academic Press; 2009.
7. Curtis C. Public Perceptions and Expectations of the Forensic Use of DNA Results of a Preliminary Study. *Bulletin of Science, Technology & Society,* 2009;29(4):313-24.
8. Fraser J, Williams R. *Handbook of forensic science*. New York, NY: Routledge; 2009.
9. Jobling MA, Gill P. Encoded evidence: DNA in forensic analysis. *Nature Reviews: Genetics,* 2004;5(10):739.
10. Robert D, Dufresne M. The social uses of DNA in the political realm or how politics constructs DNA technology in the fight against crime. *New genetics and Society*, 2008;27(1):69-82.
11. Taverne MD, Nijboer JF, Abdoel MF, Farooq S. DNA in de databank: de moeite waard? Een procesanalyse binnen de strafrechtsketen met het oog op de effectiviteit en efficiëntie van de toepassing van de Wet DNA-onderzoek bij veroordeelden. 2012. Retrieved from: http://www.trefpunteuropa.nl/9353000/1/j4nvgs5kjg27kof_j9vvhswlo9bh5xe/vj7nnfsqetyr/f=/blg211448.pdf.
12. Wilson DB, McClure D, Weisburd D. Does forensic DNA help to solve crime? The benefit of sophisticated answers to naive questions. *Journal of Contemporary Criminal Justice*, 2010;26(4):458-469.

13. Nederlands Forensisch Instituut. Nederlandse DNA-databank voor strafzaken Jaarverslag 2012. 2013. Retrieved from: http://dnadatabank.forensischinstituut.nl/dna_dossier/jaarverslagen_dna_databank/index.aspx.
14. Meulenbroek A. *De essenties van forensisch biologisch onderzoek: humane biologische sporen en DNA*. Paris; 2009.
15. Van Amelsvoort AG, Groenendal H, Van Manen J. Werkwijze bij het onderzoek op de Plaats Delict (PD) *Justitiële Verkenning*, 2004;30(4):72-83.
16. Nederlands Forensisch Instituut. DNA-databank Wet- en regelgeving. 2014, Retrieved from: https://dnadatabank.forensischinstituut.nl/wet%5Fen%5Fregelgeving/
17. Beek van de CP. Criteria voor de aanlevering van DNA-profielen aan de Nederlandse DNA-databank voor strafzaken (Versie 1.6). 2014. Retrieved from: http://dnadatabank.forensischinstituut.nl/dna_dossier/links_en_literatuurverwijzingen/handboeken_voorschriften_brochures_factsheets/.
18. Bond JW. Value of DNA evidence in detecting crime. *Journal of Forensic Sciences*, 2007;52(1):128-136.
19. Bond JW, Hammond C. The value of DNA material recovered from crime scenes. *Journal of Forensic Sciences*, 2008;53(4):797-801.
20. Asplen CH. Application of DNA Technology in England and Wales United Kingdom. 2003. Retrieved from: https://www.ncjrs.gov/pdffiles1/nij/grants/203971.pdf.
21. Williams R, Johnson P, Martin P. *Genetic information and crime investigation: social, ethical and public policy aspects of the establishment, expansion and police use of the National DNA Database*. Durham University, School of Applied Social Sciences; 2004.
22. Bruijns B, Kloosterman A, de Bruin K, van Asten A, Gardeniers J, editors. Presumptive Human Biological Trace Test for Crime Scenes, based on Lab-on-aChip Technology - "HuBiTT. 6th European Academy of Forensic Science Conference; 2012; the Hague, the Netherlands.
23. French DJ, Archard CL, Andersen MT, McDowell DG. Ultra-rapid DNA analysis using HyBeacon (TM) probes and direct PCR amplification from saliva. *Mollecular and Cellular Probes.* 2002;16(5):319-326.
24. LGC-Forensics. DNA for forensics – ParaDNA. 2013. Retrieved from: http://www.lgcgroup.com/productsservices/forensics/dna-for-forensics/paradna/.
25. Butkus B. University of Arizona Group Seeks Partner to Move Forensic Lab-on-a-Chip to Market September 13, 2012. Retrieved from: http://www.genomeweb.com/pcrsample-prep/universityarizona-group-seeks-partners-move-forensic-lab-chip-market.
26. Estes MD, Yang JN, Duane B, Smith S, Brooks C, Nordquist A, et al. Optimisation of multiplexed PCR on an integrated microfluidic forensic platform for rapid DNA analysis. *Analyst,* 2012;137(23):5510-5519.
27. Gangano S, Elliott K, Anoruo K, Gass J, Buscaino J, Jovanovich S, et al. DNA investigative lead development from blood and saliva samples in less than two hours using the RapidHIT™ Human DNA Identification System. *Forensic Science International: Genetics*, 2013;4(1):e43-e44.
28. GE Healthcare Life Sciences. DNAscan Rapid DNA Analysis System data file for forensics. 2013. Retrieved from: http://www.gelifesciences.com/webapp/wcs/stores/servlet/productById/nl/GELifeSciences/29022852.
29. Lockheed Martin IntrepID S2A-90 Brochure 2013. Retrieved from: http://www.lockheedmartin.com/content/dam/lockheed/data/isgs/documents/ISGS-IntrepIDBrochure-1-24-12.pdf.
30. Lounsbury JA, Karlsson A, Miranian DC, Cronk SM, Nelson DA, Li JY, et al. From sample to PCR product in under 45 minutes: a polymeric integrated microdevice for clinical and forensic DNA analysis. *Lab on a Chip*. 2013;13(7):1384-1393.
31. Mukhopadhyayis R. DNA microfluidics – Forensic flow. *Chemistry World*, 2011:50-3.
32. NEC Tests its Portable DNA Analyzer with Japan's National Research Institute of Police Science. November 22, 2012 Retrieved from http://www.nec.com/en/press/201211/global_20121122_02.html.
33. Tan E, Turingan RS, Hogan C, Vasantgadkar S, Palombo L, Schumm JW, et al. Fully integrated, fully automated generation of short tandem repeat profiles. *Investigative Genetics,* 2013;4:16.


R-DNA

# Chapter 3

## DNA by the Numbers[1]

*Locations of usable DNA based on 24,466 crime scene samples*

**Abstract**

Nowadays increasing numbers of evidentiary traces are collected at crime scenes and submitted for DNA analysis at the forensic laboratories. However, almost 50% of the analysed DNA samples do not result in valuable DNA typing information (1) and a few studies show that the possibility to actually obtain usable DNA profiles can depend on the trace type (2, 3). Evaluating the DNA results obtained for various sampled traces can provide us information on which traces are most promising to select for DNA analysis. Such information can guide crime scene investigators in decision-making.

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[1]The chapter was published as Mapes A. DNA by the Numbers - Locations of usable DNA based on 24,466 crime scene samples. *Forensic Magazine*, 2015;12(5):8-9. This article is single authored. The study was mainly performed by S. Verheij and T. Sijen. I would like to thank them for their valuable suggestions and recommendations and giving me the opportunity to do research on DNA success rates, which is a key subject in my dissertation. Thanks to this opportunity I came to a first model to potentially assist scene of crime officers in their trace prioritisation and selection process. This led the way for ensuing studies.

## 3.1 The Study

Six European forensic laboratories[1] from the EUROFRGEN network, gathered DNA yields from over 24,466 crime-related samples that were categorised based on biological source or sampled item. The category 'sample type' includes various biological sources such as bodily fluids and tissues and the category 'sampled item' includes several items sampled for either saliva or contact traces.
DNA yield was used to predict the DNA profiling result. Four categories were chosen based on in-house experience: 1) full profile, 2) usable partial or full profile, 3) partial profile possibly useful, and 4) no informative profile. Details on this categorisation can be found in Table 1. These four categories inform us which are the most promising samples to select for DNA analysis.

**Table 1**. DNA Yield used to Predict DNA Profiling Result Based on In-house Experience

| Expectation (standard profiling) | Yield | Input PCR if 1/10 of yield |
|---|---|---|
| No informative profile | 0 - 0.025 ng | max 2.5 pg |
| Partial profile possibly useful | 0.025 - 0.625 ng | max 62 pg |
| Partial or full usable profile | 0.625 - 5 ng | max 500 pg |
| Full profile | 5 ng | more than 500 pg |

*Multiple donors may be present*

## 3.2 Observations and Conclusions

A total of 44 categories were made for the overall categories 'sample type' and 'sampled item' (Figure 1). The number of samples in each category varies from 18 to 7104 (see 'n samples' in Figure 1) and the results represent trends. In Figure 1 for each sample category, the percentages of samples with an expected type of profile are shown: dark and middle green bars indicate full and usable profiles; a light bar represents possibly useful profiles and a brown bar marks the category no profile. Within the overall categories, the sample categories are ranked from lowest to highest percentage no profile expected.
When comparing sample types, we see for instance that for *blood* samples in 93% of the cases a full pro- file and in 4% no profiles may be obtained. For *faeces* samples, on the other hand, the percentage no profile is much higher namely 24%. This variation is also observed when comparing various sampled items likely to carry saliva or contact traces: the percentage in the 'no profile' category is 2% for balaclavas and 29% for bottle lids and 0% for coat collars and 44% for plastic bags.

[1] Six EUROFORGEN partners contributed to this study: Department of Forensic Medicine Copenhagen (UCPH, 237 samples, 2013) Netherlands Forensic Institute (NFI, 14,974 samples, 2012/2014), Institute of Legal Medicine Cologne (UHC, 228 samples, 2013/2014), Institute of Forensic Research JU Krakow (JU, 890 samples, 2013), Institute of Legal Medicine Innsbruck (IMU, 8047 samples, Dec 2012 – Nov 2013), Forensic Science Institute USC Santiago de Compostela (USC, 36 samples, 2013).

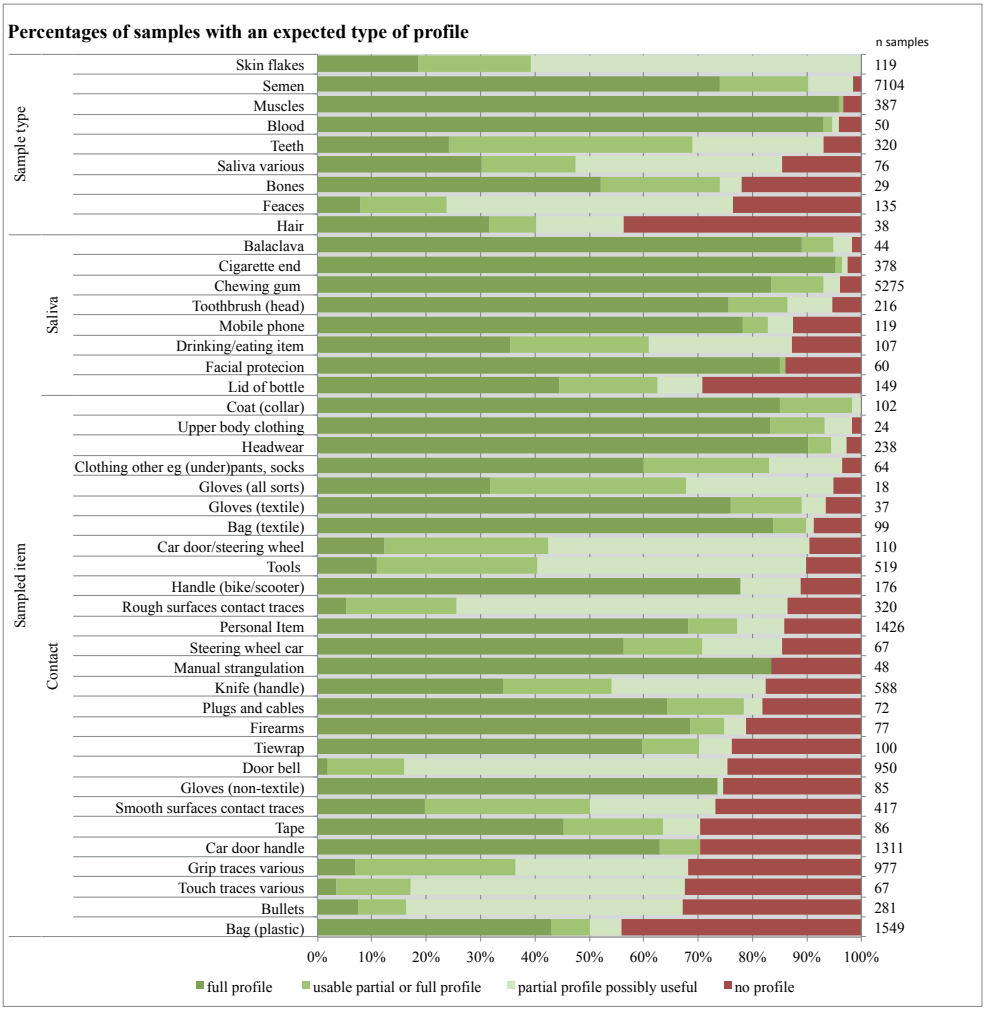


**Figure 1.** Percentages of Profiles in Four Categories that are Expected to Arise based on DNA Yield for 44 Types of Evidentiary Traces.

The proximity, intensity and duration of contact seem to contribute to profiling success as saliva items *balaclava*, *cigarette end*, *chewing gum* and *toothbrush* and contact items such as *collars* and *headwear* give high percentages of full profiles.

When regarding all categories, the five most promising samples to select are muscles, blood, coat collars, cigarette ends and balaclavas. On the other end of the spectrum, the five least promising samples are *hairs*, *plastic bags*, *bullets*, *touch traces various* and *grip traces various*. Importantly, for all categories full and useable profiles are obtained. For the sampled item bag plastic for instance 44% of the samples categorise into 'no profile' while 43% may result in a full profile.

The category *'partial profile possibly useful'* presents uncertainty as at least a partial profile is expected but it is difficult to predict whether DNA results will be usable for

comparison studies. Aspects such as the number of contributors to a profile and mixture ratios will have a role here. Notwithstanding, this collaborative study gives insight in the DNA results of the several traces and may assist crime scene investigators in their decision-making in which many other aspects such as the context of an item in to crime are relevant too.

## 3.3 How to use the Figure as CSI?

Figure 1 may assist crime scene investigators in selecting evidentiary traces for DNA analysis for which they currently use their experience. This is particularly useful when multiple traces are at hand. Clearly, selecting evidentiary traces is case-dependent and largely affected by how crime and offender related the evidentiary traces are. This leads to a four-step decision process for the selection of evidentiary traces for DNA analysis:

1) Collect evidentiary traces at the crime scene,
2) Rank crime scene traces based on crime and/or offender relatedness,
3) Use figure 1 to rank the highest crime and/or offender related traces, and
4) Select the most promising traces for DNA analysis.

For instance, at a violent burglary where the victim is injured and the perpetrator has fled the scene, a bloodstain, balaclava, and screwdriver are found. Since it is highly likely that the blood trace originates from the victim, the balaclava and screwdriver have the highest potential to provide an investigative lead towards the offender. From Figure 1 it derives that the balaclava holds more potential for successful DNA analysis than the screwdriver (compare balaclava and tool categories in Figure 1) and it seems most opportune to select the balaclava for DNA analysis in this criminal process.
Therefore, for future decisions on selecting crime scene traces for DNA analysis, it is recommended that crime scene investigators use figure 1 and the four-step decision process in their trace selection process.

## 3.4 References

1. Mapes AA, Kloosterman AD, Poot de CJ. DNA in the Criminal Justice System: The DNA Success Story in Perspective. *Journal of Forensic Sciences*, 2015;60(4):851-856.
2. Castella V, Mangin P. DNA profiling success and relevance of 1739 contact stains from caseworks. *Forensic Science International: Genetics,* 2008;1(1):405-407.
3. Raymond JJ, van Oorschot RA, Gunn PR, Walsh SJ, Roux C. Trace DNA success rates relating to volume crime offences. *Forensic Science International Genetics,* 2009;2(1):136-137.

# Chapter 4

## Knowledge on DNA Success Rates to Optimise the DNA Analysis Process: From Crime Scene to Laboratory[1]

**Abstract**

DNA analysis has become an essential intelligence tool in the criminal justice system for the identification of possible offenders. However, it appears that about half of the processed DNA samples contains too little DNA for analysis. This study looks at DNA success rates within 28 different categories of trace exhibits and relates the DNA concentration to the characteristics of the DNA profile. Data from 2260 analysed crime samples show that cigarettes, bloodstains, and headwear have relatively high success rates. Cartridge cases, crowbars, and zip ties are on the other end of the spectrum. These objective data can assist forensics in their selection process. The DNA success probability shows a positive relation with the DNA concentration. This finding enables the laboratory to set an evidence-based threshold value in the DNA analysis process. For instance, 958 DNA extracts had a concentration value of 6 pg/μL or less. Only 46 of the 958 low-level extracts provided meaningful DNA profiling data.

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[1]This chapter was published as: Mapes AA, Kloosterman AD, Marion van V, Poot de CJ. Knowledge on DNA success rates to optimise the DNA analysis process: from crime scene to laboratory. *Journal of Forensic Sciences*, 2016:61(4), 1055-1061. This study was designed, performed, analysed and published as an article by the first author. The co-authors advised on the set-up of the study and made suggestions and recommendations for the article.

## 4.1 Introduction

In the Netherlands, more than 100,000 forensic DNA analyses are performed annually. The analysed samples consist of reference samples and crime samples. This illustrates the confidence in DNA as a "silent witness" with which to identify suspects and to provide evidence in court. Furthermore, offender DNA databases have led to an exponential increase in the storage of both offender and crime trace profiles. Many countries have their own success stories on the use of offender DNA databases to identify suspects (1–4). This success story on forensic DNA typing has given the criminal justice system (CJS) the impression that the sky is the limit, so to speak. This has resulted in a steadily increasing number of requests for DNA analysis. In many countries, forensic laboratories are facing DNA backlogs (5,6). This is mainly due to the fact that Scene of Crime Officers (SoCOs) secure an increasing number of DNA samples at crime scenes, with the goal of solving more crimes. Although this policy has been successful in a number of cases, it also leads to growing backlogs both at the police forensic department and at the laboratory (7). Due to these backlogs, turnaround times are increasing (8,9), which does not benefit fast case solving and the identification of suspects. Further research into the circumstances pertaining to the backlog situation has shown that many secured DNA traces contain no or too little DNA for analysis (9–14). A recent evaluation of the DNA success story in the Netherlands has shown that 46% of analysed serious crime traces and 36% of analysed high volume crime traces produced no DNA profiling results (9). It should be noted that these traces were run through the complete analysis process, up to and including the forensic report. These results suggest that the criminal justice chain could benefit from more insight into DNA success rates. It takes time and money to secure, analyse, and report on DNA traces. Through an effective selection process, both at the sites of the police and the laboratory, the process can be made more efficient. It is expected that a thorough selection of DNA traces for analysis, based on DNA success rates, will lead to fewer unnecessary analysis activities and will therefore shorten turnaround times and reduce backlogs. To facilitate this selection process, knowledge on DNA success rates is necessary. This information could lead to creating a decision support sys- tem (15,16) for the SoCO to make evidence-based decisions on the selection of DNA traces for analysis. Research shows that knowledge-driven decisions can lead to efficient decision-taking on effective investigative actions (16). Currently, SoCOs are making decisions on the analysis of DNA traces under circumstances of uncertainty. To reduce this uncertainty, a thorough analysis on DNA success rates is the necessary first step toward creating a decision support system.

Different studies have given some insight into DNA success rates (9–11,14). For example, in a previous study, blood stains and saliva traces from cigarette ends show a high success rate in providing the CJS with DNA typing results (9). This study also

showed that 42% of processed contact traces produced no typing results. Another study (10) showed that only 26% of the contact stains yielded DNA profiles suitable for comparison with the DNA database. DNA contact traces with prolonged contact such as clothing (61%) or car items (37%) showed relatively high success rates. Two other studies (11,14) concerning "handled items" demonstrated that approximately half of the samples from the handled items did not produce a DNA profile. It was hypothesized that DNA success rates not only depend on the nature of the cellular material (blood, saliva, or epithelium) but also on the type of the exhibit sampled for DNA. Knowledge of these DNA success rates will help SoCOs to decide which traces should be submitted to the laboratory. For instance, we expect the success rate of blood traces to be much higher than the success rate of several contact traces. This is possibly due to the low DNA concentration in extracts of these contact traces, which means that also on the part of the forensic laboratory there are opportunities to make a further selection. Samples with a high DNA concentration offer a much higher success probability of obtaining a profile than samples with a low DNA concentration. Objective knowledge on the success rate of the DNA typing pro- cess in relation to the DNA concentration can be used to introduce a threshold value in the DNA analysis process. This would mean that DNA extracts are only analysed if the amount of DNA in the extract is above the set threshold value.
To introduce an actual success rate model for the decision to analyse DNA traces from different types of exhibits, the following information is relevant:

- concentration of DNA present in extracts of samples from different categories.
- characteristics of the DNA profile (single, mixed, or complex DNA profile or no typing result).
- characteristics of the obtained DNA profiles (match with suspect, victim/witness, or DNA database).

These three parameters form the basis of a decision model based on DNA success rates, which can be used by police and the forensic laboratory in the trace selection process.
Overall, we expect that knowledge of the actual DNA success rates can be used to make smart decisions on the selection of traces for further analysis, which will significantly reduce the number of "empty" traces that only encumber the DNA analysis processes. First, this knowledge can be used to guide the decision-making process of the SoCOs who select DNA traces and send them to the laboratory. Second, this knowledge will improve the DNA analysis process at the laboratory. The data for this DNA success rate study were obtained from 2260 analysed crime samples secured at the crime scene. These samples were collected and secured by police force SoCOs.

## 4.2 Materials and Methods

For this study, a dedicated set of DNA traces was selected. The DNA traces involved traces of blood that were directly secured from the crime scene, as well as exhibits that were secured from the crime scene and subsequently swabbed and sampled at the police station for DNA analysis. This dataset consists of 5754 crime samples that were analysed in the period of 1 January 2012 until 31 December 2013. These analysed samples were categorized (Table 1) in terms of 28 defined categories for evaluation, which make up the most frequent exhibit types. It was decided that for frequently sampled exhibits containing more than 100 samples, a random sample of 100 was selected for this study (17). In our study, for each trace exhibit $t$, we determined the percentage $p_t$ of cases that produced DNA profiling results. Let $N_t$ be the number of traces of exhibit $t$ in our material. The value of $p_t$ can be determined exactly by analysing all $N_t$ traces of a type $t$, but as this is rather wasteful for frequently occurring types (i.e., large $N_t$), we decided to estimate $p_t$ for frequent types using a random sample of 100 from all available traces of each exhibit (17). Sample size $n_t$ was chosen as the minimum of 100 and $Nt$. Notice that for types with $N_t \leq 100$, this procedure determines $p_t$ exactly. For very large $N_t$, a sample size of 100 would always result in a 95% two-sided confidence interval smaller than ± 0.1 (17). In our case, we have moderate $N_t$; hence, a multiplicative finiteness correction factor ($1 - n_t / N_t$) is in place, which entails that widths of confidence intervals shrink further. For the most frequent type $t$ = "weapon grip" ($N_t$ = 441), the confidence interval is not larger than ± 0.08. Less frequent types have even smaller confidence intervals, for example, for $t$ = "car items," $N_t$ = 150, the confidence interval is smaller than 0.03. In our opinion, this determines $p_t$ with sufficient accuracy. This selection process resulted in the 2260 samples used in this study.

From these selected samples, we evaluated i) the concentration of DNA present in extracts of samples from the 28 different categories (Table 1); ii) the characteristics of the DNA profiles; and iii) matching characteristics of the obtained DNA profiles (match with suspect, victim/witness or DNA database).The characteristics of the DNA profiles were further classified as i) single DNA profiles; ii) mixed DNA profiles that meet the criteria for storage in the Dutch national DNA database; iii) complex DNA profiles that do not meet the criteria for storage in the DNA database but contain typing data that can be used for exclusion; and iv) no typing result, when the profiling data contain too little information for a meaningful comparison.

For all selected crime samples, the measured DNA concentrations, the characteristics of the DNA profiles, and the matching characteristics were obtained from the case file and the testimonies of the reporting scientists.

**Table 1.** Categories and Number (Total and Selected) of Samples Evaluated in this Study for a Decision Model Based on DNA Success Rates

| Exhibit | *N* total | *N* selected | Exhibit | *N* total | *N* selected |
|---|---|---|---|---|---|
| (Fire) weapon grip | 441 | 100 | Crowbar | 78 | 78 |
| Blood | 354 | 100 | Collar | 77 | 77 |
| Fabric gloves | 273 | 100 | Torch | 77 | 77 |
| Cigarette end | 182 | 100 | Sleeve cuff | 70 | 70 |
| Screwdriver | 163 | 100 | Handle motor/bike | 67 | 67 |
| Car items | 150 | 100 | Sock | 64 | 64 |
| Tools (other) | 139 | 100 | Gas cylinder | 53 | 53 |
| Cartridge case | 137 | 100 | Shoe | 48 | 48 |
| Drinking items | 134 | 100 | Tape | 44 | 44 |
| Cap | 123 | 100 | Keys | 43 | 43 |
| Handbag grip | 118 | 100 | Glasses | 32 | 32 |
| Balaclava | 108 | 100 | Lighter | 23 | 23 |
| Knife grip | 104 | 100 | Undefined gloves | 350 | 0 |
| Zip tie | 99 | 99 | Undefined* | 853 | 0 |
| Headwear | 98 | 98 | Other† | 1165 | 0 |
| Latex gloves | 87 | 87 | *Total* | *5754* | *2260* |

**Exhibit unknown*
*†Infrequently sampled exhibits*

### 4.2.1 DNA Analysis Process of the Selected Samples

*DNA Sample Preparation*
The traces used in this study were secured from the crime scenes by SoCOs and sampled for DNA analysis at the police laboratories (18). The sampling was performed by the police laboratories using NFI standards and proto- cols. Most samples were secured by swabbing the exhibit using a dry cotton swab. At the police laboratories, the swabs were transferred to special containers and sent to the NFI. Cigarette ends were cut from the cigarette and placed in the container. Exhibits such as balaclavas and fabric gloves were sampled using the stubbing procedure (19).

*DNA Extraction and Quantification*
DNA extraction and pro- filing were performed at the NFI. At the time of this study, the DNA quantification method for DNA extracts was the Quantifiler" Duo DNA quantification kit using the 7500 Real-Time PCR System (Applied BiosystemsTM—AB). The manufacturer of the quantification kit reports a DNA concentration range of 50 ng/μL to 23 pg/μL (20). However, much lower sensitivities – even as low as 2 pg/μL – have been reported (21–23) for this quantification system. Therefore, for this study, we took all DNA concentration data into account, including the data that fell below the minimum value of the indicated concentration range of 23 pg/lL.

*DNA Profiling*

All short tandem repeat (STR) DNA profiles included in this study were obtained with the Next Generation Multiplex (NGM) DNA analysis system (AB). The NGM DNA analysis system determines the genetic information on 15 polymorphic DNA loci and the sex-specific locus amelogenin (24). DNA amplification (29 PCR cycles) and fragment analysis were performed according to the manufacturers' instruction. If necessary, post-PCR samples were reanalysed under enhanced conditions for the detection of the amplified STR fragments. Validated in-house adaptations involved either enhanced electrophoresis settings or post-PCR clean up of the amplified STR fragments. The clean up removes salts and primers that compete with amplified DNA fragments for injection into the capillary during electrophoresis and allows for increasing the signal strength of the amplified STR fragments (25).

The reporting scientist performed the interpretation and statistical evaluation of the DNA profile comparisons. DNA profiles for entry, comparison, and storage in the DNA database must meet minimal criteria (26). The Netherlands uses the CODIS DNA database software. For automated comparison, the DNA profile of the crime sample should contain the typing results of at least 6 loci. The random match probability of partial profiles to be searched should exceed the figure of 1 in 10 million (9,26). In some instances, intelligence-based database searches on complex profiles were performed as indicated by the reporting scientist.

## 4.3 Results

*DNA Quantification*

As stated above, the Quantifiler® Duo DNA quantification kit reported a DNA concentration down to 23 pg/μL. However, sensitivities as low as 2 pg/μL have been reported in the literature. Moreover, the combined DNA data from the extracts of the crime samples in this study show a continuous function for the DNA concentration in the extract down to 2 pg/μL. Although the interpretation of the quantification values of low-level DNA samples should be approached with caution, the data at least support that meaningful concentration estimates can be obtained from DNA samples that contain less than 23 pg/μL. Of 2260 samples, 641 (28%) samples had concentration values between 2 pg/μL and 23 pg/μL, and 700 (31%) extracts had values below 2 pg/μL.

*DNA Profiling*

We evaluated the DNA profiling results of 2260 samples. From 1120 (50%) of the traces, no DNA profiling results were obtained; 290 traces (13%) resulted in complex DNA profiles that did not meet the quality criteria for DNA database storage; and 850 traces (38%) yielded profiling results that met the quality criteria (26) for DNA database

**Table 2.** Characteristics of the Obtained DNA Profiling Results

| | | | Concentration* (pg/μL) | |
|---|---|---|---|---|
| DNA profiling results | Number | % | Mean | St.dev |
| Single | 573 | 25 | 628.4 | 1462.5 |
| Mixed | 277 | 12 | 186.4 | 213.2 |
| Complex | 290 | 13 | 52.0 | 62.6 |
| No result | 1120 | 50 | 3.1 | 5.0 |
| Total | 2260 | 100 | 170.7 | 0.6 |

**The concentration data of outliers with more than 3 times the original st.dev were not taken into consideration for calculating the mean concentration.*

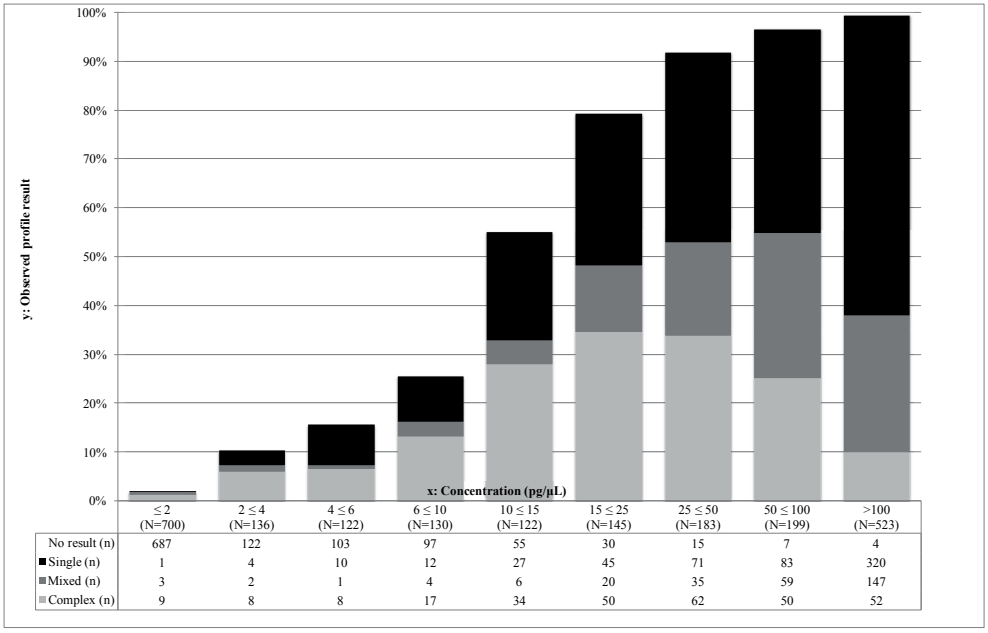
storage (Table 2). Table 2 shows that samples that yielded profiling results contained higher concentrations of DNA than samples that did not lead to profile results.

To form a complete picture, all traces were plotted from lowest to highest measured concentration (Fig. 1), giving more insight into the pattern of concentrations toward obtaining certain DNA profile results. Figure 1 indicates that samples with higher DNA concentrations have a higher success probability than samples with a low DNA concentration. The data from Fig. 1 and Table 2 show a positive relation between DNA concentration and the success probability. When the mean concentration increases, the DNA profiling results improve.

This relation was not dependent on the category of the sampled exhibit. Between the different categories of exhibits, the proportion of samples with a DNA concentration of less than 10 pg/μL that yielded no DNA profiles was comparable. For high-level DNA with a concentration of 10 pg/μL or more, the same trend was observed. Based on these results, we can conclude that the obtained profile result of the DNA typing process depends on the amount of DNA, independent of the nature of the sampled exhibits.

Practically, all traces with a concentration higher than 100 pg/μL yield DNA profiles that meet the quality criteria for DNA database storage. In our study, 23% of the extracts (Fig. 1) contained more than 100 pg/μL of DNA. Only 4 traces with a concentration higher than 100 pg/μL (Fig. 1) resulted in a profile that did not meet the quality criteria for DNA database storage, due to the fact that they were too complex (mixed) and therefore had insufficient discriminative factors to perform a DNA comparison study. At the other end of the spectrum, Fig. 1 shows that practically all traces that had a measured concentration of 2 pg/μL or less resulted in no DNA profiling results; this applied for 31% of all traces.

Between these extremes, the success rates are harder to predict. This applied for 46% of the traces. Setting a threshold value within that range will therefore always result in a loss of DNA profiling data. For example, setting a conservatively low threshold at 2 pg/μL would mean that 31% (700/2260) of the samples can be set aside after the quantification step (Fig. 1). A DNA profiling result was obtained from only 13 of these 700 samples, of which 9 were complex profiles. Above the 2 pg/μL threshold, 72% of




| | ≤ 2 (N=700) | 2 ≤ 4 (N=136) | 4 ≤ 6 (N=122) | 6 ≤ 10 (N=130) | 10 ≤ 15 (N=122) | 15 ≤ 25 (N=145) | 25 ≤ 50 (N=183) | 50 ≤ 100 (N=199) | >100 (N=523) |
|---|---|---|---|---|---|---|---|---|---|
| No result (n) | 687 | 122 | 103 | 97 | 55 | 30 | 15 | 7 | 4 |
| Single (n) | 1 | 4 | 10 | 12 | 27 | 45 | 71 | 83 | 320 |
| Mixed (n) | 3 | 2 | 1 | 4 | 6 | 20 | 35 | 59 | 147 |
| Complex (n) | 9 | 8 | 8 | 17 | 34 | 50 | 62 | 50 | 52 |

**Figure 1.** Histogram Showing the Positive Relation Between the Success Probabilities and the DNA Concentration.
The table shows the actual number of obtained DNA profiles within the given concentration intervals.

the traces produced a DNA profiling result. This must be compared to the no-threshold situation where only 50% of the traces produced a DNA profiling result.

A less conservative threshold (i.e., 6 pg/μL) would mean that 42% (958/2260) of the traces would not need further analysis (Fig. 1). In this case, we would lose profiling results in about 5% (46/958) of the cases.

At the other extreme, if the threshold was to be set at a value of 100 pg/μL, this would mean that practically all traces would yield a DNA profiling result. This high threshold would however result in a much higher loss of samples that could potentially produce a DNA profiling result. In our study, 36% (621/1737) of the samples contained less than 100 pg/μL of DNA but still produced a DNA profiling result.

*Different Type of Exhibits*

Table 3 shows the obtained DNA profile success rates for a range of different exhibits. Successful exhibits can be understood as having a high DNA concentration (average ≥ 100 pg/μL) or a high success probability (≥ 80%). The DNA success probabilities in Table 3 show that cigarette ends, blood, balaclava, headwear (other), ball caps, collars, sleeve cuffs, and socks are the exhibits with the highest success rate. Unsuccessful exhibits have a low DNA concentration (average ≤ 5.0 pg/μL) or a low success ≤ 5.0 probability (≤ 20%), and these include cartridge cases, crowbars, keys, tape, zip ties, and gas cylinders.

Samples secured from ball caps show the highest success probability (94%) in obtaining DNA profiling results. It was also observed that a large proportion of the sampled ball caps yielded mixed DNA profiles. Cigarette ends also have a high success probability (87%). However, practically all these DNA profiles were single DNA profiles (84%). Although ball caps show the highest success probability in obtaining a DNA profiling result, we observed higher concentrations of DNA in extracts from cigarette ends, bloodstains, balaclavas, and headwear (other).

In some cases, similar categories of exhibits show comparable success rates, for instance, the sleeve cuff and collar. This suggests that it might be sufficient to sample either the sleeve cuff or the collar of a clothing item when seeking to identify the wearer of this item.

Screwdrivers, crowbars, and other tools belong to roughly the same category (hand-tools). However, there was a significant difference between the type of tool and the DNA concentration obtained at the $p < 0.01$ level (one-way ANOVA: $F(2, 262 = 5.717$, $p = 0.004$). Post hoc comparison using the LSD Fisher test revealed that screwdrivers showed a significantly higher DNA concentration than crowbars and hand-tools (other). Crowbars and hand-tools (other) did not significantly differ from each other. The same trend was observed for the success probabilities.

Other similar exhibits like gloves of latex and gloves of fabric show a significant difference at the $p < 0.01$ level in measured DNA concentrations (one-way ANOVA: $F(1, 180) = 14.095$, $p < 0.001$). The same trend was observed for the success probabilities.

The lowest DNA concentrations were observed in the exhibit categories of gas cylinder, zip tie, keys, and tape. Although we obtained a DNA profiling result from 15% of the samples from zip ties, in half of the cases theses profiles match the victim. Samples from tapes show the same picture.

Profiles fit for comparison were also evaluated for their matching features (Table 3). Whether a DNA profile from a crime sample has an added value for the criminal investigation depends on the circumstances of the case. In most cases, the goal is to identify a suspect or to find evidence to link the suspect with the crime. However, in some cases, it can be important to obtain a match with a victim, for instance to find DNA traces of the victim on the clothes or in the car of the suspect.

When a balaclava was sent in for DNA analysis, a DNA pro- file was obtained in 92% of the cases. In 37% of these cases, a match was obtained with a person in the DNA database, and in 21%, a match with a known suspect. Samples from the grip of (fire) weapons have a 26% success probability in obtaining DNA profiling data. In only 12% of the cases, these profiles matched a person in the DNA database, but in 38% of the cases, a match with a known suspect was obtained. At 62%, DNA pro- files from ball caps have the highest success probability of obtaining a DNA match with a person; most of these matches are DNA database matches.

**Table 3.** DNA Success Rates Ranked from Highest to Lowest Mean Concentration

| Trace exhibit | *N* (Σ=2260) | Observed profile results (%) | | | | Concentration (pg/µL)* | | Observed (%) matches† | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Single | Mixed | Complex | No result | Mean | Stdev | Database | Suspect | Victim/ witness |
| Cigarette end | 100 | 84 | 3 | 0 | 13 | 1602.4 | 2843.4 | 10 | 36 | 12 |
| Blood | 100 | 68 | 6 | 7 | 19 | 920.2 | 2310.6 | 10 | 27 | 44 |
| Balaclava | 100 | 46 | 29 | 17 | 8 | 386.3 | 583.6 | 37 | 21 | 0 |
| Headwear (other) | 98 | 27 | 34 | 29 | 10 | 266.8 | 350.4 | 32 | 17 | 7 |
| Ball cap | 100 | 42 | 39 | 13 | 6 | 255.03 | 271.3 | 50 | 12 | 0 |
| Collar | 77 | 34 | 26 | 20 | 20 | 224.8 | 311.3 | 43 | 5 | 0 |
| Sleeve cuff | 70 | 29 | 34 | 19 | 18 | 147.5 | 157.5 | 42 | 5 | 2 |
| Sock | 64 | 38 | 25 | 20 | 17 | 94.5 | 165.8 | 38 | 2 | 7 |
| Handbag grip | 100 | 9 | 15 | 23 | 53 | 79.7 | 127.6 | 30 | 11 | 9 |
| Fabric glove (inside) | 100 | 33 | 24 | 21 | 22 | 75.8 | 129 | 21 | 13 | 0 |
| Torch | 77 | 27 | 12 | 9 | 52 | 64 | 151 | 43 | 14 | 0 |
| Drinking items | 100 | 57 | 6 | 8 | 29 | 60.7 | 82.8 | 8 | 27 | 8 |
| Shoe | 48 | 21 | 17 | 17 | 45 | 29.7 | 47.6 | 50 | 0 | 0 |
| Knife grip | 100 | 19 | 4 | 7 | 70 | 24.3 | 78.3 | 20 | 7 | 40 |
| Latex glove (inside) | 87 | 16 | 9 | 24 | 51 | 21.6 | 30.4 | 26 | 23 | 0 |
| Lighter | 23 | 17 | 4 | 17 | 62 | 14.1 | 16.3 | 22 | 11 | 11 |
| (Fire) weapon grip | 100 | 6 | 9 | 11 | 74 | 13.9 | 29.5 | 12 | 38 | 4 |
| Car items | 100 | 14 | 2 | 13 | 71 | 13 | 22.3 | 21 | 7 | 7 |
| Handle motor/bike | 67 | 9 | 6 | 16 | 69 | 10.7 | 16.1 | 24 | 10 | 0 |
| Screwdriver | 100 | 7 | 5 | 19 | 69 | 10.2 | 14.6 | 25 | 9 | 6 |
| Glasses | 32 | 19 | 0 | 3 | 78 | 8.5 | 17.8 | 6 | 9 | 0 |
| Cartridge case | 100 | 6 | 4 | 4 | 86 | 8.5 | 20.8 | 14 | 29 | 0 |
| Hand-tools (other) | 100 | 9 | 5 | 7 | 79 | 6 | 9.1 | 33 | 0 | 10 |
| Crowbar | 78 | 0 | 3 | 8 | 89 | 5.1 | 7.2 | 22 | 22 | 0 |
| Tape | 44 | 9 | 0 | 2 | 89 | 4.5 | 14.4 | 25 | 0 | 50 |
| Keys | 43 | 12 | 2 | 2 | 84 | 3.4 | 6.4 | 25 | 25 | 0 |
| Tie-wrap | 99 | 6 | 0 | 9 | 85 | 3 | 5 | 7 | 0 | 47 |
| Gas cylinder | 53 | 0 | 0 | 0 | 100 | 1.1 | 2.1 | 0 | 0 | 0 |

**On average 2 outliers (Table 1) per exhibit were removed (min=1, max= 6). For example secured bloodstains had a mean concentration of 1459.3 pg/µL, after removing 1 outlier with a concentration of 54.8 ng/µL the mean concentration was 920.2 pg/µL.*

*†The success probabilities in obtaining a match (with the database, suspect or victim/witness) were calculated on the basis of the number of samples that gave DNA profiling results. A total of 46 DNA profiles did not match a person but matched the DNA profile of another crime sample in the database.*

## 4.4 Conclusions and Discussion

This study was performed to gain more insight into forensic DNA success rates and to help build an objective decision model for the analysis of DNA traces based on these DNA success rates. First, it was hypothesized that DNA success rates vary across different types of exhibits that are sampled for DNA, so that a model that incorporates this factor can assist the SoCOs in
their selection process when examining crime scenes for biological trace evidence. Second, it was hypothesized that DNA success rates depend on the concentration of DNA, so that a carefully chosen threshold value may lead to a more efficient DNA profiling process at the laboratory.
The overall DNA profiling results from 2260 samples showed that 50% of the samples that were sampled and sent in by SoCOs for DNA analysis at the NFI did not yield a DNA typing result. The high number of negative profiling results from this study concurs with the results from our previous study which showed that 46% of the serious crime traces analysed at the NFI did not yield a DNA profile (9). Of the 1140 samples (50% of total) that did yield a DNA profiling result, 75% met the quality criteria for entering, searching, and storing in the DNA database. The DNA concentration obtained and the DNA profiling results from the crime scene samples relate to each other, and this is in agreement with the expectation that the DNA concentration value is a key factor to obtain successful DNA profiling results. With increasing DNA concentrations, the number of DNA profiles that meet the criteria for DNA database storage increases (Fig. 1). This finding appears to be independent of the exhibit sampled and therefore implies that any threshold set in the DNA profiling process only depends on the quantification result.
The observed pattern of average DNA concentrations of the different exhibits, combined with the success probability of obtaining a DNA profile, differed between the different types of sampled exhibits (Table 3). Cigarette ends, blood, balaclava, headwear (other), ball caps, collars, sleeve cuffs, and socks show the highest DNA success rates, while cartridge cases, crowbars, keys, tape, zip ties, and gas cylinders show the lowest DNA success rates. This information can assist the SoCO in prioritising traces for DNA profiling.
Samples from gas cylinders show extremely low quantification measures, and none of the analysed gas cylinder samples produced a DNA profiling result. The same applies to samples from the tape and zip tie exhibits, with very low DNA quantities measured and, respectively, 11% and 15% producing a DNA profile. It is worth asking whether these traces should still be collected by SoCOs and submitted for the DNA profiling process. In robberies, the perpetrator often uses tape and zip ties to immobilize the victim. In these cases, the exhibits are secured by the SoCOs for DNA analysis to identify the perpetrator. However, 50% of the obtained profiles from the tape and 47%

of the obtained profiles from the zip tie matched the victim. The actual success rate to obtain the DNA profile from a suspect is therefore even lower.

Such information should be considered when traces are collected at the crime scene or when they are selected for further analysis at the forensic laboratory. In serious crime cases, a success rate of 15% or lower can probably justify the selection and processing of such traces for DNA analysis. This might not be true for less serious crimes, however. It should be noted that the actual decision on whether or not to analyse a DNA trace might therefore be case dependent. For instance, a low success rate trace such as a zip tie could still be selected for DNA profiling in a murder case, but not in a burglary case. We expect that the introduction of a decision model based on DNA success rates will lead to evidence-based selection of traces and exhibits by the police and a better use of the DNA profiling capacity at the forensic laboratory. In addition, the forensic laboratory can improve the efficiency of the DNA profiling process by introducing a threshold value for the minimum amount of DNA in a sample. When profiling DNA samples, the procedure starts with quantifying the amount of DNA in the sample. If the estimated DNA concentration does not exceed a set threshold value, no DNA profiling will be performed on the sample extract.

For decisions on setting the threshold value, the method of quantification is essential. In this study, the samples were quantified with the Quantifiler® Duo. The lowest reported sensitivity of this quantification system is 2 pg/μL, which would allow the threshold value to be set at 2 pg/μL. Furthermore, there is a clear positive relation between the measured DNA concentration in the extract and the DNA profiling result. The data from this study can therefore be used to objectively justify the decision on the height of the threshold value.

The data from this study showed that 98% of the samples with an estimated DNA concentration of 2 pg/μL or less produced no profiling result. Of the 2260 samples, 31% had a concentration of less than 2 pg/μL (Fig. 1). Setting the threshold at this value in routine DNA analysis would thus imply that 31% of the samples could be rejected for analysis after quantification of the extract. The probability that any of these samples would produce a meaningful profiling result is low (less than 2%), and of the profiles that were obtained, most proved too complex to use.

Setting a less conservative threshold (i.e., 6 pg/μL) would expedite the laboratory process even further: in that case, some 42% of the extracts would likely be rejected for further processing. Using the higher threshold value, we observed that DNA profiling data were obtained in less than 5% of the samples with a concentration value of less than 6 pg/μL (Fig. 1). In more than half of the cases, however, the profiling data obtained from these low-level DNA samples did not meet the quality criteria for searching and storing in the DNA database. This shows that introducing a threshold value in the forensic DNA analysis process can be very effective, saving capacity, time, and money for the forensic laboratories and the CJS. If forensic laboratories perform their own study

to obtain a threshold value, we expect similar results. However, the laboratory-specific value will likely be codetermined by their specific protocols for sample collection and the systems used for DNA analysis. The quantification method used is another key issue. The data in this study were obtained with a relatively less sensitive quantification method. Recently, more sensitive quantification methods have become available such as the AluQuant (27). The new quantification methods will allow for a more precise determination of the threshold value, reducing the risk that low-level DNA samples are set aside for analysis.

A decision model based on DNA success rates can be used by the police and the laboratory to reduce the number of "empty" traces that encumber the DNA analysis processes: on the one hand by enabling SoCOs to make knowledge-based judgments in their trace selection process for DNA analysis and on the other hand by introducing a threshold value for the quantification step of DNA analysis at the laboratory. It is expected that SoCOs will be more aware of what to sample at the crime scene, thereby reducing backlogs and turnaround times, as "empty" DNA traces will be rejected for the complete DNA analysis pro- cess at the forensic laboratory. Information on DNA success rates can thus form the basis for such evidence-based decisions and may result in an actual decision support system for the SoCOs for the selection of DNA traces for analysis. Although using such systems during the intelligence phase of a crime case within the police and forensic field is still explorative (15,16,28,29), we do expect this to offer a way forward in optimising crime scene investigations.

The data of this study can furthermore serve to create evidence-based decision models for the use of new and mobile DNA technologies for future crime scene work. Several manufacturers are marketing mobile DNA technologies to further optimise forensic DNA testing as an investigative tool (30–35). To make optimal use of these mobile technologies, knowledge of the properties of biological traces that allow for fast mobile analysis or that require the expertise of a fully equipped forensic DNA typing laboratory is then essential.

## 4.5 References

1. Corte-Real F. Forensic DNA databases. *Forensic Science International*, 2004;146:143S–4S.
2. Ruitberg CM, Reeder DJ, Butler JM. STRBase: a short tandem repeat DNA database for the human identity testing community. *Nucleic Acids Research*, 2001;29(1):320–322.
3. Schneider PM, Martin PD. Criminal DNA databases: the European situation. *Forensic Science International*, 2001;119(2):232–8.
4. Netherlands Forensic Institute. Illustration Exponential Growth of the Dutch DNA Databases for Crime Cases. Retrieved from: https://dnadatabank.forensischinstituut.nl/resultaten/groei_dna_databank_strafzaken/index.asp.
5. Fine GA. Review of the Federal Bureau of Investigation Laboratory's Forensic DNA Case Backlog, 2010, US Department of Justice Office of the Inspector General. Retrieved from: https://oig.justice.gov/reports/FBI/a1039.pdf (accessed June 4, 2015).
6. Pinchin R. Eliminating DNA backlog. *Forensic Magazine,* 2007;4(4): 32–36.
7. Nelson M. Making sense of DNA Backlogs, 2010: Myths vs. Reality. National Institute of

Justice, Office of Justice Programs, US Department of Justice. 2010. Retrieved from: https://www.ncjrs.gov/pdffiles1/nij/232197.pdf.
8. Duceman B. Decreased Turn-Around Time for Forensic Genetic Testing. 2006. Retrieved from: https://www.ncjrs.gov/App/Publications/abstract.aspx?ID=233444.
9. Mapes AA, Poot de CJ, Kloosterman AD. DNA in the criminal justice system: the DNA success story in perspective. *Journal of Forensic Science*, 2015;60(4):851–856.
10. Castella V, Mangin P. DNA profiling success and relevance of 1739 contact stains from caseworks. *Forensic Science International: Genetics,* 2008;1(1):405–407.
11. Raymond JJ, van Oorschot RA, Gunn PR, Walsh SJ, Roux C. Trace DNA success rates relating to volume crime offences. *Forensic Science International Genetics*, 2009;2(1):136–137.
12. Bond JW. Value of DNA evidence in detecting crime. *Journal of Forensic Sciences* 2007;52(1):128–136.
13. Bond JW, Hammond C. The value of DNA material recovered from crime scenes. *Journal of Forensic Sciences,* 2008;53(4):797–801.
14. Harbison S, Fallow M, Bushell D. An analysis of the success rate of 908 trace DNA samples submitted to the Crime Sample Database Unit in New Zealand. *Australian Journal of Forensic Sciences,* 2008;40(1):49–53.
15. Camacho-Collados M, Liberatore F. A decision support system for predictive police patrolling. *Decision Support System*, 2015;75:25–37.
16. Shen Q, Keppens J, Aitken C, Schafer B, Lee M. A scenario-driven decision support system for serious crime investigation. *Law Probability and Risk*, 2006;5(2):87–117.
17. Neave HR. *Statistical tables for mathematicians, engineers, economists and the behavioural and management sciences*. London, U.K.: George Allen & Unwin, 1978.
18. Netherlands Forensic Institute. DNA-Basis Met Vooronderzoek Door de Politie (HBS004) Retreived from: https://mijnnfi.nl/pdc/biologisch/dna-haar-vinger-sporen-bloed/dna-basis-met-vooronderzoek-door-de-politie.html.
19. Bruin de KG, Verheij SM, Veenhoven M, Sijen T. Comparison of stubbing and the double swab method for collecting offender epithelial material from a victim's skin. *Forensic Science International Genetics*, 2012;6(2): 219–223.
20. Applied Biosystems Quantifiler Duo DNA Quantification Kit User's Manual. Retrieved from: https://www3.appliedbiosystems.com/cms/groups/applied_markets_support/documents/generaldocuments/cms_049050.pdf.
21. Barbisin M, Fang R, O'Shea CE, Calandro LM, Furtado MR, Shewale JG. Developmental Validation of the Quantifiler" Duo DNA Quantifica- tion Kit for Simultaneous Quantification of Total Human and Human Male DNA and Detection of PCR Inhibitors in Biological Samples. *Journal of Forensic Sciences*, 2009;54(2):305–319.
22. Roinestad I, Green R. Developmental validation of the Quantifiler" Real-Time PCR Kits for the quantification of human nuclear DNA samples. *Journal of Forensic Sciences*, 2005;4:809–825.
23. Sawin A, Harrah H, Jason Chute M, Staton P. A Comparative Analysis of Quantifiler Duo and Plexor" HY DNA Quantification Systems. Retrieved from: http://www.marshall.edu/forensics/files/2012/09/Sawin-Andrew-Poster-2-7-11.pdf.
24. Applied Biosystems. AmpFLSTR" NGM SElectTM Express Kit. Retrieved from: http://www.lifetechnologies.com/order/catalog/product/4415021.
25. Westen AA, Nagel JH, Benschop CC, Weiler NE, de Jong BJ, Sijen T. Higher capillary electrophoresis injection settings as an efficient approach to increase the sensitivity of STR typing. *Journal of Forensic Sciences*, 2009;54(3): 591–598.
26. Beek van de CP. Criteria Voor de Aanlevering van DNA-Profielen aan de Nederlandse DNA-Databank Voor Strafzaken (Versie 1.6). Retrieved from: http://dnadatabank.forensischinstituut.nl/dna_dossier/links_en_literatuurverwijzingen/handboeken_voorschriften_brochures_factsheets/.
27. Mandrekar MN, Erickson AM, Kopp K, Krenke BE, Mandrekar PV, Nelson R, et al. Development of a human DNA quantitation system. *Croation Medical Journal* 2001;42(3):336–339.
28. Biedermann A, Bozza S, Garbolino P, Taroni F. Decision-theoretic analysis of forensic sampling criteria using Bayesian decision networks. *Forensic Science International*, 2012;223(1):217–27.
29. He P, Tao WA. Design of criminal investigation expert system based on CILS. *Journal of Software*, 2011;6(8):1586–1593.
30. Dawnay N, Ahmed R, Naif S. The ParaDNA" Screening System – a case study in bringing forensic R&D to market. *Science and Justice,* 2014;54 (6):481–486.

31. Hennessy LK, Mehendale N, Chear K, Jovanovich S, Williams S, Park C, et al. Developmental validation of the GlobalFiler" Express Kit, a 24- marker STR Assay, on the RapidHIT System. *Forensic Science International Genetics,* 2014;13:247–258.
32. LaRue BL, Moore A, King JL, Marshall PL, Budowle B. An evaluation of the RapidHIT system for reliably genotyping reference samples. *Forensic Science International Genetics,* 2014;13:104–111.
33. GE Healthcare Life Sciences. DNA scan Rapid DNA Analysis System Data File for Forensics. Retrieved from: http://www.gelifesciences.com/webapp/wcs/stores/servlet/productById/nl/GELifeSciences/29022852.
34. Lounsbury JA, Karlsson A, Miranian DC, Cronk SM, Nelson DA, Li JY, et al. From sample to PCR product in under 45 minutes: a polymeric integrated microdevice for clinical and forensic DNA analysis. *Lab on a Chip,* 2013;13(7):1384–1393.
35. White M. Police Trial on-the-Spot DNA Testing Machines. Retrieved from: http://news.sky.com/story/1316007/police-trial-on-the-spot-dna-testing-machines.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# Chapter 5

## Objective Data on DNA Success Rates can Aid the Selection Process of Crime Samples for Analysis by Rapid Mobile DNA Technologies[2]

**Abstract**

Mobile Rapid-DNA devices have recently become available on the market. These devices can perform DNA analyses within 90 min with an easy 'sample in–answer out' system, with the option of performing comparisons with a DNA database or reference profile. However, these fast mobile systems cannot yet compete with the sensitivity of the standard laboratory analysis. For the future this implies that Scene of Crime Officers (SoCOs) need to decide on whether to analyse a crime sample with a Rapid-DNA device and to get results within 2 h or to secure and analyse the sample at the laboratory with a much longer throughput time but with higher sensitivity. This study provides SoCOs with evidence-based information on DNA success rates, which can improve their decisions at the crime scene on whether or not to use a Rapid-DNA device. Crime samples with a high success rate in the laboratory will also have the highest potential for Rapid-DNA analysis. These include samples from e.g. headwear, cigarette ends, articles of clothing, bloodstains, and drinking items.

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This study was designed, performed, analysed and published as an article by the first author. The co-authors advised on the set-up of the study and made suggestions and recommendations for the article.

## 5.1 Introduction

Nowadays, DNA analysis and comparing DNA profiles is a key element of forensic science. While in reality the DNA analysis process from crime scene to result can take days, weeks or even months, the TV-series *CSI* performs fictional DNA analysis within minutes. This so-called '*CSI-effect'* affects the public expectations (1). Science is starting to catch up with fiction and the actual forensic community is urging to speed up the DNA analysis process. Especially in high profile cases such as terrorism cases or serial murder and rape cases every minute can count. In this light the Netherlands Forensic Institute (NFI) has recently developed a fast DNA analysis track, called DNA 6-hours (2). Another technological trend is the introduction of mobile Rapid DNA devices that can perform DNA analysis within 90 minutes with an easy 'sample in – answer out' system: the so-called Rapid DNA analysis. The unique selling point of the mobile DNA-technology is that it can be taken to the crime scene and operated by the Scene of Crime Officers (SoCOs). This enables to start up the DNA analysis process immediately. The introduction of mobile DNA devices in the criminal justice system is therefore inevitable.

Rapid DNA devices are designed for several purposes. In the field of medicine, for instance, Rapid DNA technologies are being developed to rapidly detect viruses, bacteria or infectious diseases such as malaria or HIV from samples (3-5). These technologies also hold out promise for forensics; for instance, to determine the presence of the male and female variants of the amelogenin gene to indicate the presence of DNA as a screening test (6).

In addition, several companies in the field of forensics are working on rapid human identification systems to indicate the presence of DNA or to perform complete DNA profiling outside the laboratory with easy-to-use handheld systems. These systems operate as fully integrated and automated DNA analysis systems that produce high-quality STR-profiles suitable to perform comparisons with a DNA database or reference profile. Such technologies include the RapidHIT200 by IntegenX, ParaDNA by LGC forensics and DNAscan by NetBio. Other promising technologies are IntrepID by Lockheed-Martin and ZyGEM, Portable DNA Analyzer by NEC and MIDAS by the former Forensic Science Service.

Several studies on these mobile technologies have shown that robust buccal swab DNA profiles can be used for identification purposes (7-9). This progress has even led to the establishment of a quality assurance standard for DNA data-basing laboratories that perform Rapid DNA analysis using a Rapid DNA instrument for the analysis of reference samples (i.e. offender, arrestee, detainee or casework reference sample) for direct comparison with or inclusion in the Combined DNA Index System (CODIS) (10). This further ensures the quality and integrity of typing data from mobile devices.

Mobile Rapid DNA systems are currently used for the analysis of buccal samples when comparison with a DNA database is the objective. This is due to the fact that these samples contain sufficient DNA for mobile analysis. It is unclear at present what quantity and quality of DNA is needed to obtain profiles with Rapid technologies. The quantity of DNA that is needed for these Rapid DNA systems is high compared to standard laboratory DNA analysis. Sensitivity studies report different DNA quantity requirements (7-9, 11-14). For instance, partial DNA profiles were obtained from samples containing 5 ng DNA on a cotton swab (12). This study also showed that when the DNA was directly added to the sample cartridge, complete profiles could be obtained from 500 pg of DNA, and partial profiles with 65% of the alleles present could be detected down to 25 pg of DNA. NetBio even demonstrated that a complete STR profile could be obtained from 1 ng of purified DNA (7). However, the potential consequences of mobile DNA technologies for the analysis of crime samples are not discussed in these studies.

With this limitation, some studies on Rapid DNA do show successful typing results from crime scene DNA samples (7, 14-16), indicating that mobile technologies can provide investigative leads (15). The threshold for analysing DNA samples – i.e. the actual sensitivity of the mobile devices – is unclear, as there are limited studies on this matter. However, the sensitivities of the mobile devices will be lower than standard analysis at the laboratory and the sample is also (partly) consumed when using a mobile analysis technology. On the one hand, using these devices may offer an early investigative lead; on the other hand, it entails the risk of losing a sample that could have led to a profile in the lab. It is important to recognise both the opportunities and the risks associated with analysing crime samples with mobile technologies.

When mobile Rapid DNA devices are integrated at the police forensic department, SoCOs have to decide whether to use a Rapid DNA device to analyse a crime sample or to forward the crime sample to the laboratory, in a situation of uncertainty. This is because the results and effects of using a Rapid DNA device are unknown. To reduce the uncertainty, information should be made available about the possibilities and risks of rapidly analysing crime samples. Although information on the success rates of crime samples analysed with Rapid DNA devices is still insufficient, relevant information about these outcomes can in first instance be obtained from laboratory data. All forensic DNA laboratories have DNA typing data available from different trace exhibits and with different DNA contents. Based on these data, the outcomes of Rapid DNA devices can be estimated.

At the NFI we have a dataset containing 2260 DNA crime samples (obtained in a previous study (17)). This dataset was used to estimate the potential results obtained with the less sensitive mobile Rapid DNA analysis systems. Estimations based on these data might support the SoCOs in their decisions to either use a mobile Rapid DNA device to analyse the crime sample or to send the sample to the Crime Lab.

## 5.2 Materials & Methods

For this study we used a set of 2260 analysed crime samples from 28 different trace exhibit categories obtained in a previously published study (17) (Table 1).
From these samples we obtained the case files with details on crime samples. Based on the testimonies from the reporting scientists we obtained information on the concentration of the DNA in the extracts of the samples and the characteristics of the DNA profile. The DNA profiles were classified as 1) single DNA profiles; 2) mixed DNA profiles that meet the criteria for storage in the Dutch national DNA database; 3) complex DNA profiles that do not meet the criteria for storage in the DNA database but contain typing data that can be used for exclusion; and 4) no typing result, when the profile data contains too little information for a meaningful comparison.
This dataset was used to analyse the potential impact of the lower sensitivity levels of the mobile DNA analysis systems. The literature suggests that mobile technologies are able to process DNA samples with DNA quantities of 100 pg/µL (6, 11) in the extract. Some results of these studies even show that extracts with DNA quantities of at least 25 pg/µL (11) were able to yield partial profiles. To illustrate the impact on obtaining profiles with less sensitive devices, we arbitrarily decided on two sensitivity levels for the mobile technology to estimate the potential results, a somewhat conservative level of 100 pg/µL and a more sensitive level of 25 pg/µL. Although currently unrealistic, this sensitivity level may well be achieved in the future.
Laboratory data on DNA typing results were used to estimate the potential of mobile DNA technologies with a lower sensitivity level. The success rates of numerous crime sample categories were evaluated at an analytical threshold value of 100 pg/µL and of 25 pg/µL.
Due to this reduced sensitivity of the mobile DNA technology compared to the lab, we needed to define an additional outcome of this Rapid DNA device, namely the false negative. A false negative indicates that the DNA in the extract generated a profile in the laboratory but the amount of DNA in the sample fell below the sensitivity level of the mobile device (arbitrarily set at either 100 pg/µL or 25 pg/µL). This means that the extract yielded a profiling result in the lab, but is expected not to provide a profile when analysed with a Rapid DNA device.
For each crime sample category we analysed the actual DNA typing results. For a number of categories we analysed the DNA typing results at thresholds of 100 pg/µL and 25 pg/µL. The DNA profiling results above and below these sensitivity levels were evaluated. If the laboratory obtained a profiling result from samples that contained DNA below these sensitivity levels (set at 100 pg/µL and 25 pg/µL), they were marked as a false negative.
The potential impact of these lower sensitivity levels on the analysis results can be used to indicate the effect of any sensitivity level for DNA analysis in the future.

**Table 1.** Actual Observed DNA Profiling Results
The actual observed profiling results are ranked from highest to lowest success rates (single + mixed + complex DNA profiles). Traces above the dotted line indicate the most successful trace categories. *Based on Table 3 from Mapes. et al., 2016 (17)*

| | | Observed profile results (%) | | | | Concentration (pg/µL)* | |
|---|---|---|---|---|---|---|---|
| Trace exhibit | *N* (Σ=2260) | Single | Mixed | Complex | No result | Mean | Stdev |
| Ball cap | 100 | 42 | 39 | 13 | 6 | 255.03 | 271.3 |
| Balaclava | 100 | 46 | 29 | 17 | 8 | 386.3 | 583.6 |
| Headwear (other) | 98 | 27 | 34 | 29 | 10 | 266.8 | 350.4 |
| Cigarette end | 100 | 84 | 3 | 0 | 13 | 1602.4 | 2843.4 |
| Sock | 64 | 38 | 25 | 20 | 17 | 94.5 | 165.8 |
| Sleeve cuff | 70 | 29 | 34 | 19 | 18 | 147.5 | 157.5 |
| Blood | 100 | 68 | 6 | 7 | 19 | 920.2 | 2310.6 |
| Collar | 77 | 34 | 26 | 20 | 20 | 224.8 | 311.3 |
| Fabric glove (inside) | 100 | 33 | 24 | 21 | 22 | 75.8 | 129 |
| Drinking items | 100 | 57 | 6 | 8 | 29 | 60.7 | 82.8 |
| Shoe | 48 | 21 | 17 | 17 | 45 | 29.7 | 47.6 |
| Latex glove (inside) | 87 | 16 | 9 | 24 | 51 | 21.6 | 30.4 |
| Torch | 77 | 27 | 12 | 9 | 52 | 64 | 151 |
| Handbag grip | 100 | 9 | 15 | 23 | 53 | 79.7 | 127.6 |
| Lighter | 23 | 17 | 4 | 17 | 62 | 14.1 | 16.3 |
| Handle motor/bike | 67 | 9 | 6 | 16 | 69 | 10.7 | 16.1 |
| Screwdriver | 100 | 7 | 5 | 19 | 69 | 10.2 | 14.6 |
| Knife grip | 100 | 19 | 4 | 7 | 70 | 24.3 | 78.3 |
| Car items | 100 | 14 | 2 | 13 | 71 | 13 | 22.3 |
| (Fire) weapon grip | 100 | 6 | 9 | 11 | 74 | 13.9 | 29.5 |
| Glasses | 32 | 19 | 0 | 3 | 78 | 8.5 | 17.8 |
| Hand-tools (other) | 100 | 9 | 5 | 7 | 79 | 6 | 9.1 |
| Keys | 43 | 12 | 2 | 2 | 84 | 3.4 | 6.4 |
| Zip tie | 99 | 6 | 0 | 9 | 85 | 3 | 5 |
| Cartridge case | 100 | 6 | 4 | 4 | 86 | 8.5 | 20.8 |
| Crowbar | 78 | 0 | 3 | 8 | 89 | 5.1 | 7.2 |
| Tape | 44 | 9 | 0 | 2 | 89 | 4.5 | 14.4 |
| Gas cylinder | 53 | 0 | 0 | 0 | 100 | 1.1 | 2.1 |

** On average 2 outliers per exhibit were removed (min=1, max= 6). For example, secured bloodstains (category "blood") show a mean concentration of 1459.3 pg/µL; after removing 1 outlier with a concentration of 54.8 ng/µL, the mean concentration was 920.2 pg/µL.*

### 5.2.1 DNA Analysis Process of the Selected Samples[1]

*DNA sample preparation*

The traces we used in this study were secured from the crime scenes by SoCOs and sampled for DNA analysis at the police laboratories. The sampling was performed by the police laboratories using NFI standards and protocols. Most samples were secured by swabbing the exhibit using a dry cotton swab. At the police laboratories the swabs were transferred to special containers and sent to the NFI. Cigarette ends were cut from

[1] This information on the analysis process was published previously in an article on DNA success rates (17).

the cigarette and placed in the container. Exhibits such as balaclavas and fabric gloves were sampled by the stubbing procedure (18).

*DNA extraction and quantification*
DNA extraction from the secured samples and the profiling were performed at the NFI. In the course of this study the DNA quantification method used for DNA extracts was the Quantifiler® Duo DNA quantification kit with the 7500 Real-Time PCR System (Applied Biosystems™ - AB). The manufacturer of the quantification kit reports a DNA concentration range of 50 ng/µL to 23 pg/µL (19).

*DNA profiling*
All Short Tandem Repeat (STR) DNA profiles included in this study were obtained with the Next Generation Multiplex (NGM) DNA analysis system (AB). The NGM DNA analysis system determines the genetic information on 15 polymorphic DNA-loci and the sex specific locus Amelogenin (20). DNA amplification (29 PCR cycles) and fragment analysis were performed according to the manufacturer's recommendations except for validated in-house adaptations (i.e. enhanced detection of PCR fragments (21)).
The reporting scientist performed the interpretation and statistical evaluation of the DNA profile comparisons. DNA profiles for entry, comparison and storage in the DNA database must meet minimal criteria (22). In some instances, intelligence-based database searches on complex profiles were performed as indicated by the reporting scientist.

## 5.3 Results & Discussion

The purpose of this study was to understand the potential impact of analysing crime samples with a mobile Rapid DNA analysis system, which can produce profiling results within 2 hours but is less sensitive than laboratory techniques. A dataset of 2260 DNA samples, containing 28 different categories of trace items, was analysed for this purpose. Table 1 shows the actual observed profiling results of the 28 trace exhibit categories ranked from highest to lowest success rates. DNA samples
from ball caps, for instance, show a total of 94% obtained profiles of which 42% single, 39% mixed and 13% complex profiles. At the other end of the spectrum, no profiling results were obtained from DNA samples from gas cylinders.
DNA success rates are related to the concentration of the DNA in the extract obtained from the crime scene (17). Samples with low quantities of DNA are therefore less appropriate for analysis with less sensitive techniques, such as Rapid DNA devices. Crime samples that show a high success rate in the laboratory will therefore also have the highest potential for Rapid DNA analysis. The dotted line in Table 1 indicates the categories with the highest success rates. The DNA categories below this line show

success rates ranging from 55% all the way down to 0%. The categories with the highest success rates consist of ball caps, balaclavas, other headwear, cigarette ends, socks, sleeve cuffs, bloodstains, collars, fabric gloves and drinking items. These categories show DNA success rates ranging from 71% up to 94%.

The objective of using a mobile Rapid DNA device is to quickly obtain informative knowledge on the donor of a crime DNA sample through a rapid profiling procedure, which can immediately be compared to the profiles in the DNA database or to known reference samples. To obtain this goal, it is recommended to limit the rapid DNA analysis of traces at the crime scene to DNA samples with high success rates.

To evaluate the potential impact of a technique with a lower sensitivity level we focused on the categories with the highest (>70%) success rates. It is noted that samples in these categories (above the dotted line in Table 1) mainly contain saliva-stained exhibits and/or have fabric-type surfaces, while samples from categories with lower success rates consist of items with smoother, plastic types of surfaces. This illustrates that the difference in surface material is an important factor that should be considered when choosing traces for (Rapid) DNA analysis.

DNA samples from these rather successful trace exhibit categories, of which 70% or more resulted in a profile, were selected and further analysed to understand the impact of applying techniques with different sensitivities for profiling DNA samples. For this purpose we took two hypothetical sensitivity values: 100 pg/µL and 25 pg/µL. Figure 1 clearly shows the impact if the samples from these "high success rate" categories were to be analysed with a less sensitive technology. A false negative indicates that the quantity of DNA in the extract is below the sensitivity threshold. In these cases it is expected that the less sensitive mobile analysis system will not yield a profiling result.

Many samples in the "high success rate" categories show DNA concentrations lower than 100 pg/µL. If these samples were analysed with a technology that allows for a sensitivity of 100 pg/µL DNA in the extract, this would result in loss of information. Samples from most categories would then produce no profiling results in more than half of the cases, with a high number of false negatives where the standard laboratory method would have obtained a valid typing result.

For instance, profiling results were obtained from balaclava samples in 92% of the cases at the laboratory (46% single profiles, 29% mixed profiles and 17% complex profiles). With a sensitivity level of 100 pg/µL, it is expected that the balaclava samples would show a profiling result in only 61% of the cases. In 31% of the cases the less sensitive mobile technology would produce a false negative result. In these cases the mobile analysis system would fail to produce potentially valuable DNA profiling information, and by using the system, investigators might run the risk of losing potentially valuable DNA profiling data. The 31% false negative results consisted of 13% single DNA profiles, 10% mixed profiles and 8% complex profiles.

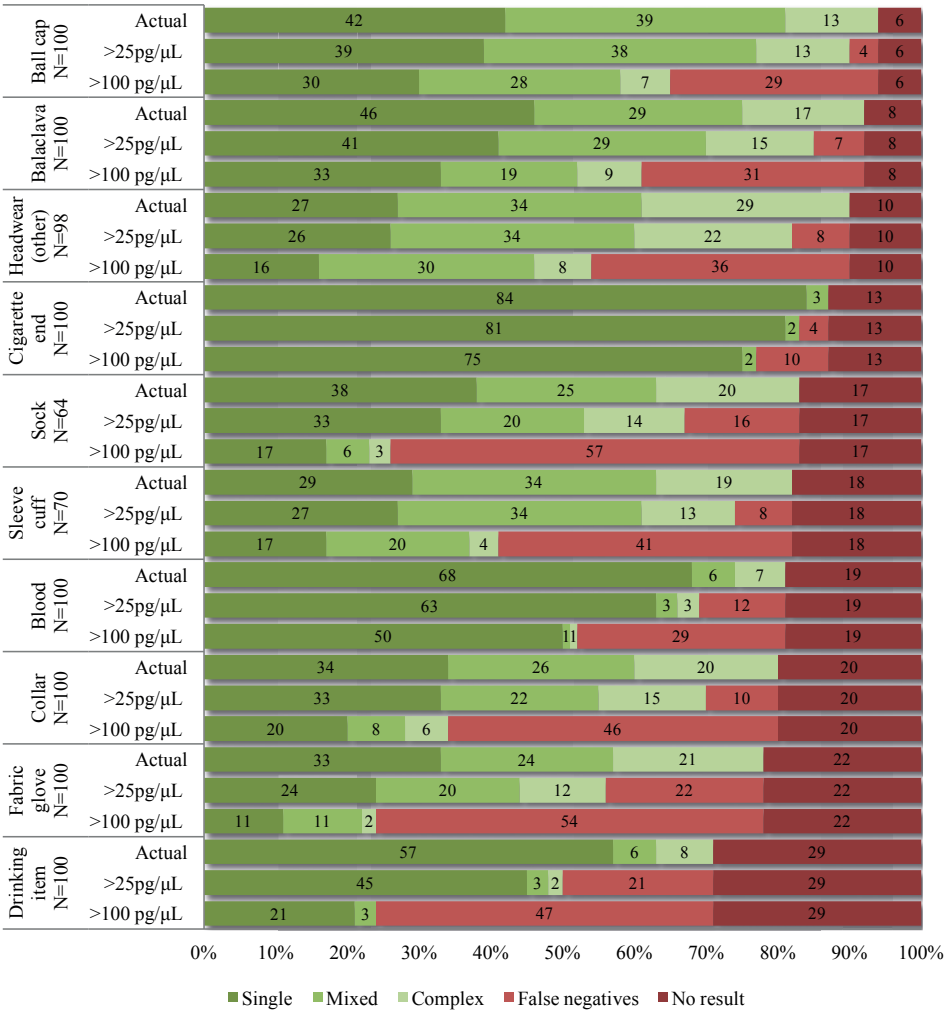



**Figure 1.** Observed Profile Results Actual, Above 25 pg/µL and Above 100 pg/µL
This figure shows the effect on the actually observed profile results from several trace exhibits when having a sensitivity level of 25 pg/µL or 100 pg/µL. A false negative indicates that the amount of DNA in the extract is above the sensitivity level of the laboratory analysis, but below the sensitivity level of the mobile device (set at either 100 pg/µL or 25 pg/µL).

The information in Figure 1 can be used to decide whether to analyse a sample with a fast but less sensitive mobile DNA-analysis system, or to analyse it in the laboratory. This decision will depend on the possibility to analyse mixed and/or complex DNA samples with mobile devices and on the extent to which false negatives are acceptable in a certain situation. If, for instance, the Rapid DNA devices are only designed to profile and compare single DNA profiles, probably only samples from cigarette ends and blood should be considered for fast mobile analysis.

However, if Rapid DNA devices enable the analyses of mixed DNA samples at a sensitivity level of 100 pg/µL (see Figure 1), then the picture changes. For instance, if a 70% success rate with a Rapid DNA device is acceptable, thus accepting 30% false negative results (complex profiles and false negatives), then one can safely decide to analyse samples from cigarette ends (10% false negative results) and bloodstains (30% false negative results).

The picture would change dramatically if future generations of mobile DNA devices achieve even more sensitive analyses. If a sensitivity level of 25 pg/µL could be reached and the technology also enables the analysis of mixed samples, then samples from ball caps (17% false negative results), balaclavas (22% false negative results), headwear (30% false negative results) cigarette ends (4% false negative results), blood (15% false negative results), collars (25% false negative results) and drinking items (23% false negative results) could all be considered for analysis.

However some categories show high numbers of complex profiles obtained, such as fabric gloves (21%) and headwear (29%). Although complex profiles do not always lead to valuable information, they can sometimes exclude or include a person's profile and can therefore provide relevant information. Consequently, if these complex profiling data cannot be processed, the number of false negative results will increase. Rapid DNA-devices that can also analyse complex profiles would therefore be most optimal.

With the current state of Rapid DNA devices, where DNA quantities of at least 100 pg/µL in the extract are needed, these systems cannot yet make a significant contribution to the crime scene for the analysis of biological traces. However, such a decision depends also on the percentage of false negatives that is considered acceptable, and this most probably varies depending on the type of case. For the efficient use of a Rapid DNA device, the decision to accept a certain number of false negatives is crucial. The Criminal Justice System needs to decide on an acceptable risk of losing evidence.

For instance, accepting false negatives could be more justifiable in burglary cases than in a murder case. On the other hand, in terrorism cases or serial murders every second can count. In those cases a fast typing result can be crucial to identifying a suspect. Obviously, the number of traces available at the crime scene must also be taken into account.

An important issue that should be mentioned about these mobile Rapid DNA devices is that they do not allow for the quantification of a sample prior to analysis. As stated in a previous article, the limitation of a Rapid DNA system is the inability to quantify the amount of DNA added to the PCR step (23). The development of a mobile quantification module might be crucial for an optimal mobile analysis of casework samples. Information on the DNA quantity can help decide whether to progress the DNA sample with the Rapid DNA device or to forward the sample to the forensic laboratory. Such a technique is not available so far, so that SoCOs need to make decisions on analysing DNA samples with uncertainty. Knowledge of DNA success rates that take reduced

sensitivities into account, as shown in Figure 1, can then offer them some degree of support. The results of this study should not be used to rush implementation, but this study can help to develop new working methods for the Criminal Justice System for the use of these mobile Rapid DNA technologies at the crime scene.

## 5.4 Conclusion

Until actual data on the sensitivity of mobile Rapid DNA technologies for the analysis of crime scene samples become available, only laboratory data on DNA success rates, as shown in Table 1, can aid the crime scene sample selection process. Our study illustrates that it is crucial to understand the possible risks of losing profiling data (Figure 1) before an objective decision can be made to use a Rapid DNA device on a crime sample. This will reduce the number of false negatives (samples that contain enough DNA for laboratory analysis but produce no typing result with the mobile technology) and allow for a better use of fast mobile DNA analysis and the potential identification of perpetrators.

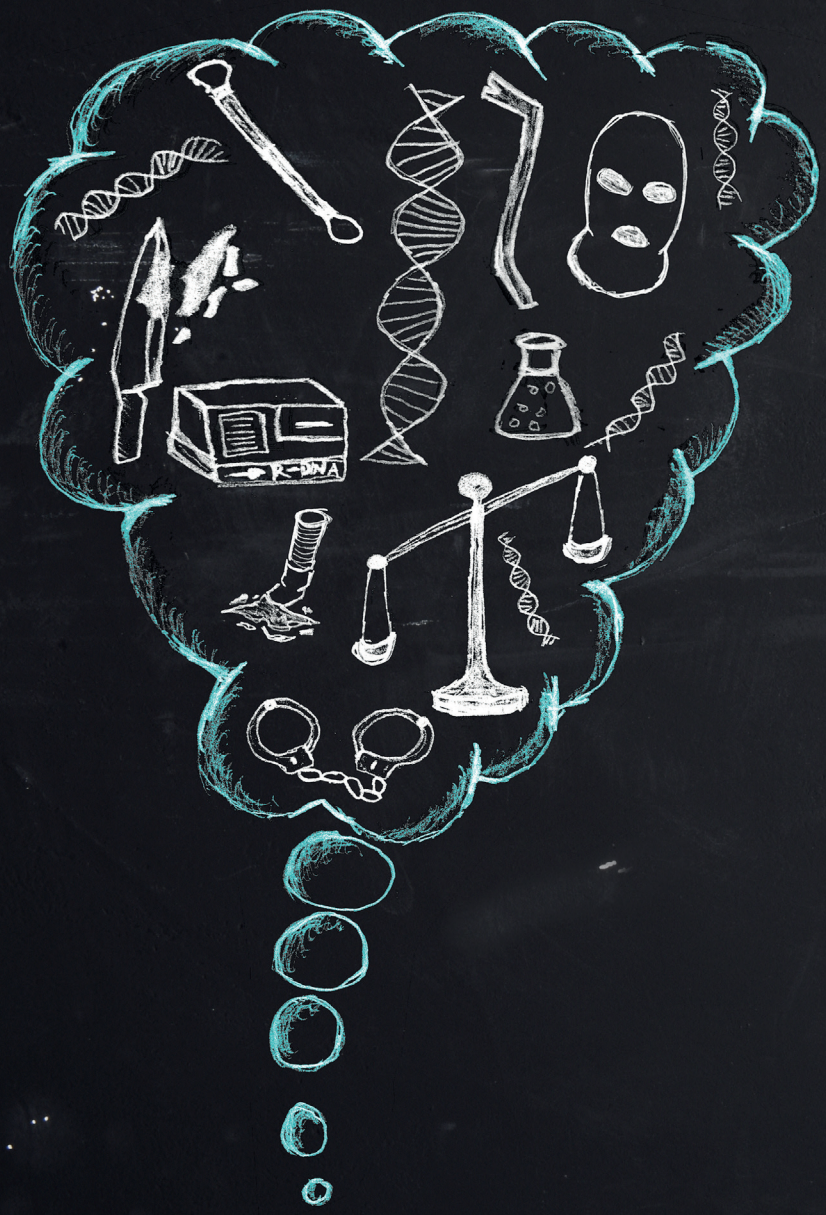
The results of this study can help SoCOs to make evidence-based decisions on the crucial decision: to analyse a DNA sample with a Rapid DNA analysis device and accept false negatives and to potentially identify the perpetrator quickly; or to forward the sample to the laboratory, where it takes longer before the results are obtained but where the probability of obtaining a profiling result is greater due to the higher sensitivities of the laboratory techniques.

It is claimed that with the use of mobile Rapid DNA technologies, perpetrators can be identified within hours (24). The mission of the SoCO is to assist the legal system in solving crimes through the investigation of the forensic evidence and to identify perpetrators quickly. However, it is unacceptable if the new mobile DNA technology entails a high risk of losing potentially incriminating evidence. The data from this study combined with comprehensive selection criteria for the crime scene workers can reduce that risk.

## 5.5 References

1. Schweitzer NJ, Saks MJ. The CSI effect: Popular fiction about forensic science affects the public's expectations about real forensic science. *Jurimetrics,* 2007:357-364.
2. Verheij S, Harteveld J, Sijen T. A protocol for direct and rapid multiplex PCR amplification on forensically relevant samples. *Forensic Science International: Genetics,* 2012;6(2):167-175.
3. Kilianski A, Haas JL, Corriveau EJ, Liem AT, Willis KL, Kadavy DR, et al. Bacterial and viral identification and differentiation by amplicon sequencing on the MinION nanopore sequencer. *GigaScience,* 2015;4(1):12.
4. University of Otago. Revolutionary handheld DNA diagnostic unit allows lab-quality analysis in the field. 2014. Retrieved from http://www.otago.ac.nz/news/news/otago077848.html.
5. Whiterow P. Epistem readies submission for TB test launch. 2013. Retrieved from: http://www.proactiveinvestors.com.au/companies/news/41352/epistem-readies-submission-for-tb-test-launch-41352.html.

6. Genedrive. Forensics Amelogenin. Retrieved from: https://www.genedrive.com/idseries/amelogenin.php.
7. Tan, E. Sample Collection System for DNA Analysis of Forensic Evidence: Towards Practical, Fully-Integrated STR Analysis. NetBio Inc., United States of America: 2011. Retrieved from: https://pdfs.semanticscholar.org/7c17/02ec56bf54483b0318cff8a5405343a46295.pdf.
8. Dawnay N, Ahmed R, Naif S. The ParaDNA® Screening System—A case study in bringing forensic R&D to market. *Science & Justice*. 2014;54(6):481-486.
9. Jovanovich S, Bogdan G, Belcinski R, Buscaino J, Burgi D, Butts EL, et al. Developmental validation of a fully integrated sample-to-profile rapid human identification system for processing single-source reference buccal samples. *Forensic Science International: Genetics*, 2015;16:181-194
10. Addendum to the quality assurance standards audit for DNA databasing laboratories performing rapid DNA analysis and modified rapid DNA analysis using a rapid DNA instrument. 2014. Retrieved from: https://www.fbi.gov/about-us/lab/biometric-analysis/codis/rapid-dna-addendum-to-qas-final-effective-12-1-2014.
11. Hennessy LK, Franklin H, Li Y, Buscaino J, Chear K, Gass J, et al. Developmental validation studies on the RapidHIT™ human DNA identification system. *Forensic Science International: Genetics,* 2013;4(1):e7-e8.
12. Hennessy LK, Mehendale N, Chear K, Jovanovich S, Williams S, Park C, et al. Developmental Validation of the GlobalFiler® Express Kit, a 24-marker STR Assay, on the RapidHIT® System. *Forensic Science International: Genetics*, 2014; 13:247-258.
13. LaRue BL, Moore A, King JL, Marshall PL, Budowle B. An evaluation of the RapidHIT system for reliably genotyping reference samples. *Forensic Science International: Genetics*, 2014;13:104-111.
14. Dawnay N, Stafford-Allen B, Moore D, Blackman S, Rendell P, Hanson EK, et al. Developmental Validation of the ParaDNA® Screening System-A presumptive test for the detection of DNA on forensic evidence items. *Forensic Science International: Genetics*, 2014;11:73-79.
15. Gangano S, Elliott K, Anoruo K, Gass J, Buscaino J, Jovanovich S, et al. DNA investigative lead development from blood and saliva samples in less than two hours using the RapidHIT™ Human DNA Identification System. *Forensic Science International: Genetics,* 2013;4(1):e43-e44.
16. Verheij S, Clarisse L, van den Berge M, Sijen T. RapidHIT™ 200, a promising system for rapid DNA analysis. *Forensic Science International: Genetics,* 2013;4(1):e254-e255.
17. Mapes AA, Kloosterman AD, Marion van V, Poot de CJ. Knowledge on DNA success rates to optimise the DNA analysis process: from crime scene to laboratory. *Journal of Forensic Sciences*, 2016:61(4), 1055-1061.
18. De Bruin KG, Verheij SM, Veenhoven M, Sijen T. Comparison of stubbing and the double swab method for collecting offender epithelial material from a victim's skin. *Forensic Science International: Genetics,* 2012;6(2):219-223.
19. Applied Biosystems®. Applied Biosystems Quantifiler® Duo DNA Quantification Kit User's Manual. 2012. Retrieved from: https://www3.appliedbiosystems.com/cms/groups/applied_markets_support/documents/generaldocuments/cms_049050.pdf.
20. Applied Biosystems®. AmpFLSTR® NGM SElect™ Express Kit. Retrieved from: http://www.lifetechnologies.com/order/catalog/product/4415021.
21. Westen AA, Nagel JH, Benschop CC, Weiler NE, De Jong BJ, Sijen T. Higher capillary electrophoresis injection settings as an efficient approach to increase the sensitivity of STR typing. *Journal of Forensic Sciences*. 2009;54(3):591-598.
22. Van de Beek CP. Criteria voor de aanlevering van DNA-profielen aan de Nederlandse DNA-databank voor strafzaken (Versie 1.6). 2014. Retrieved from: http://dnadatabank.forensischinstituut.nl/dna_dossier/links_en_literatuurverwijzingen/handboeken_voorschriften_brochures_factsheets/.
23. Holland M, Wendt F. Evaluation of the RapidHIT™ 200, an automated human identification system for STR analysis of single source samples. *Forensic Science International: Genetics,* 2015;14:76-85.
24. O'Neill S. New DNA tests will identify killers in hours. 2014. Retrieved from: http://www.thetimes.co.uk/tto/news/uk/crime/article4159345.ece?shareT.


R-DNA

# Chapter 6

## Rapid DNA Analysis at a Mock Crime Scene[1]

*The Impact on Collecting and Analysing DNA Traces*

**Abstract**

Mobile Rapid DNA technologies are currently under development for forensic intelligence purposes and might serve as a promising tool in a criminal investigation. However, the effect on current procedures when implementing such a new and rapid technology at the crime scene is unclear. For this purpose, an experimental observation-based study was designed where 40 certified Scene of Crime Officers performed a mock crime scene investigation, either with or without the opportunity of a mobile Rapid DNA analysis. This study focused on the effect of a Rapid DNA analysis option on the decisions to collect, select and analyse DNA traces. It was found that the presence of a Rapid DNA device significantly impacted the decision to analyse DNA traces. When Rapid DNA analysis is possible, participants analysed significantly more DNA traces. In addition, a great variety of DNA traces were analysed rapidly, including various low copy number DNA traces. Participants showed to lack using some kind of "frame work" in their decision-making process, including a lack of DNA success rate knowledge. This study suggests that evidence-based information on DNA success rates, together with a hierarchical decision model, could improve future crime scene investigation processes.

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[1]This chapter is accepted for publication at the *Journal of Forensic Sciences* as: Mapes AA, Poot de CJ. Rapid DNA analysis at a mock crime scene - The impact on collecting and analysing DNA traces.
This study was designed by both authors. The experiments and analyses were performed by the first author. The article was written by the first author with contributions from the co-author.

## 6.1 Introduction

Since the beginning of forensic DNA analysis, and the possibility of using a DNA database for matching crime traces to samples of known offenders, only a few studies have experimentally analysed whether DNA helps to solve crimes (1-7). These few studies show that DNA contributes to the criminal investigation in identifying unknown offenders. Currently, technologies are being developed to perform Rapid DNA analysis. With these techniques, DNA analyses might make a more significant contribution to identifying suspects and solving crimes. These technologies can analyse DNA traces within 2 hours, which means that it is possible to obtain identification results of potential offenders whilst the crime scene investigation is still on-going (8-10).

Rapid DNA technology brings about a technology driven change in the practice of the crime scene investigation. The promise of such advancements is that the effectiveness and efficiency in controlling crime and identifying offenders will be improved (11-13). Whether this capability can be reached in practice remains unclear. Although there is much theoretical discussion about the impact of technologies on police work, there are only a few empirical and evidence-based studies on the way in which new technologies are used during police work, and integrated within the police organisation (11-21). A main issue most empirical studies share is that the analyses are based on surveys or previous case data of several cases or crime scenes. Knowledge on the way new technologies are implemented in practice, and comparisons between traditional methods and methods supported by new technologies, are often lacking. More focus is needed on how to incorporate scientific and technological innovations; to increase the value of forensic investigations, and provide new means to solve crimes (22). When promising new tools emerge like Rapid DNA analysis at the crime scene, which could influence the work processes of professionals in the legal system, a thorough 'real-world' experimental analysis is essential. The best time to conduct a study concerned with the effects of new technologies on the work processes of professionals is before the technology becomes routine practice (6). In that case, the results of the study can be used to successfully implement the new technology.

In general, new information processing techniques influence and transform the cognitive system, and the operational activities of practitioners in the field (23). When observing the introduction of a new technology into a field of practice, any behavioural changes observed in practitioners help us to understand how activities could be performed in a novel way, what opportunities and risks are involved, and how this process can be further optimised (23, 24).

To understand the influence of new technologies on the behaviour, working methods and the decision processes of Scene of Crime Officers (SoCOs), SoCOs need to be observed during their work in the current situation, without these new devices, and in the new situation, where the new devices can be used. In this way, the consequences of

the new technologies can be measured. This information can be used to develop a thorough implementation plan, including new working methods that can help to maximise the opportunities, and avoid the risks associated with the use of these new technologies.

For instance, Rapid DNA technology allows analysis of samples in 2 hours that could quickly generate intelligence for the criminal investigation and may improve improve crime scene investigative practice. However, SoCOs might focus too much on finding and analysing DNA traces, in order to receive this rapid identification information, at the cost of other relevant traces. It is well known that investigators are prone to seeking confirmation for their theories, and are less focused on falsifying their hypotheses (25-27). Rapid identification techniques can deliver information on alleged perpetrators very quickly, when database matches are interpreted as perpetrator identifications. These quick identifications might also stop SoCOs from completing a further search for relevant traces, because they think they have solved the case. This can lead to missing relevant evidence, to an overvaluation of matching traces, and to an undervaluation of other relevant non-matching traces (28, 29).

Before these technologies can safely be used during crime scene investigations, we need to find out how we can overcome these risks, and seize the opportunities these technologies entail. Consequently, we need to find out more precisely how the availability of these Rapid DNA technologies influences the collection, selection and analysis of DNA traces at a crime scene.

*From Crime Scene Trace to Rapid DNA Profile*

The DNA investigative process consists of recognising traces, collecting traces for potential further analysis, selecting traces that are the most promising for further analysis, and deciding which traces are most suitable to analyse, either rapidly or in the laboratory. The challenge for any SoCO is to detect and recognise relevant physical traces as evidence in a criminal case, prior to any analysis (30, 31). A previous publication, using data from the same experimental observation study we use for the current research, focused on the detection of available traces. This study showed no influence of the availability of mobile DNA devices on the detection of traces (25). However, it is unclear what happens after SoCOs have recognised and detected DNA traces in their search. According to different scholars in this field, the collection, selection, and decision to analyse traces depends on the context of a case. This context includes: the general observations of the SoCOs, the background information they get before or after they enter the crime scene, their expertise, and the hypotheses set up to evaluate the evidence (32-34). In addition, it is suggested that SoCOs could be guided through this process of selecting evidentiary traces and deciding on analysing DNA samples when working on a case by a four-step decision model comprising of: 1) collecting traces, 2) ranking traces on crime and/or offender relatedness, 3) ranking

traces on success rates and 4) selecting the most promising trace(s) for DNA analysis (35). To our knowledge there is no systematic empirical literature discussing the decision process for selecting and analysing DNA traces.
The aim of this study is to explore how the processes of collecting selecting traces for analysis works in practice, and how this process is influenced by the availability of a Rapid DNA device. For this purpose, a mock crime scene of a violent home robbery was designed. Participating SoCOs were invited to investigate the mock crime scene. The SoCOs either worked under standard conditions in the control group, or had the opportunity to use Rapid DNA analysis in the experimental group. In this way, the effect of a Rapid DNA opportunity at the crime scene on collecting, selecting and analysing DNA traces was examined, and it was explored on which grounds SoCOs decide to select traces for analysis, and on which grounds they decide to analyse traces either rapidly or at the laboratory. By investigating these aspects, knowledge on having a Rapid DNA device at the crime scene is gained. This can be used to develop methods that help SoCOs to be better guided in their future DNA analysis decision process.

### 6.1.1 Hypotheses and Assumptions

The aim of the study is to examine the processes of collecting and selecting traces for analysis in practice, and to explore how this process is influenced by the availability of a Rapid DNA device.
In comparison with SoCOs in the control condition, it is expected that SoCOs who have the opportunity to use a Rapid DNA analysis device will shift their focus towards DNA traces during crime scene investigation, which will result in:

1. collecting more DNA traces
2. selecting more DNA traces for analysis

In the decision process of selecting DNA traces for analysis we expect SoCOs in general to:

1. use some kind of framework to select and analyse traces through considering the crime scene and/or the perpetrator/victims relatedness of the trace.
2. take into account the type of DNA traces (blood, saliva, contact or interdisciplinary) and their DNA success rates as factors in the triage process when making a decision for DNA analysis, either rapid or at the laboratory.

## 6.2 Materials & Methods

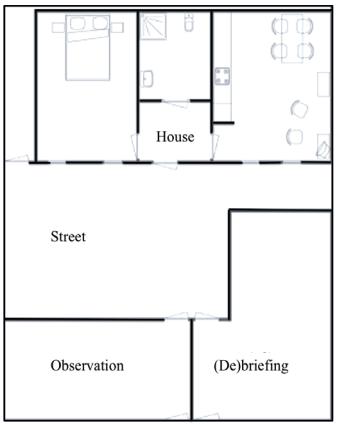


**Figure 1.** Crime house

The observation study was set up as a joint research study to analyse the effect of bringing mobile identification techniques to the crime scene[1]. This article focuses on part of the data collected for this study. The study was conducted at a mock crime scene in a 'crime house' that allows video and audio recording (Figure 1). Using a mock crime scene made it possible to build the exact same crime scene for each participant. This way, the influence of the independent measure (the presence or absence of a rapid DNA device) could be measured under the same conditions. The data collection required a staff of 4 persons and was a joint effort by the whole team of the overall project.

For each individual SoCO, the study started with a briefing in which the study, and a short account of the discovered crime were explained. Next, the participant was sent to the crime scene to conduct the investigation. In this process, a member of the research team, who posed as a trainee SoCO, accompanied the participant. The trainee's role was to gain information on decision processes made at the crime scene by the participant. Each participant was instructed to search the crime scene and secure traces, in the same way as they would do in a real investigation. They had to decide which traces they wanted to secure, which traces they wanted to be analysed, and which traces they would like to keep in storage.

To measure the effects of having a Rapid DNA analysis opportunity on the selection and investigation of traces, participants were distributed over two conditions: the Rapid DNA group, who had the opportunity to analyse traces rapidly at the mobile laboratory containing a Rapid DNA analysis device, and the control group who conducted the crime scene investigation as they would normally do.

Finishing up the investigation, the SoCOs were asked to write down their scenario about what had happened, and all the analysed traces were discussed explicitly.

After the mock crime scene investigation, the SoCOs had to perform a thought experiment. During this experiment the SoCOs in the Rapid DNA group were asked to explain what they would have done with the traces they collected at the mock crime scene if they had worked under standard conditions, and SoCOs in the control group were asked what they would have done with the collected traces if they had a Rapid DNA analysis option.

[1] The set up of this experiment has been previously partly described in an article that focused on the impact of rapid information on creating scenarios (25).

Finally, the SoCOs had to fill out a questionnaire on DNA success rates and the study ended with an interview on the experience and performance of the experiment.

### 6.2.1 Experimental Set-up

*Mock crime scene scenario - a violent home robbery*
The case we used for this study was based on a combination of real home robbery cases. In the scenario used the victim (no criminal record) was attacked at night whilst coming home from the pub by 2 perpetrators wearing gloves and face protection. Earlier that night the victim's father (criminal record for, amongst other things, dealing of drugs) came by and gave him (the victim) a substantial sum of money and a small safe containing a package. The victim decided to hide the package and money in a 'safer place'. One perpetrator molested the victim and tied him up while the other perpetrator searched the house for the money and drugs. While molesting the victim, perpetrator 1 got hurt and left a blood trace on the tap and in the sink in the bathroom. The victim's neighbour heard noises, and after shouting to the victim she decided to call the emergency services. The perpetrators fled the scene, where perpetrator 2 threw away his balaclava in a garbage can outside. The neighbour saw one perpetrator fleeing after which she went out to the crime scene, at the same time the police arrived.
*Traces*
In this study we consider a 'trace' as "all types of traces, swabs and items collected from the crime scene, victim, witness or perpetrator for scientific analysis and/or potential use as evidence" (36). For DNA analysis such a trace can also be latent and either swabbed immediately at the crime scene or later, when the item can be taken from the scene.
The interior of the crime scene was furnished and decorated as if a 29-year-old male was living there. To create the crime scene and obtain the most realistic traces the scenario was actually played in the crime house, by three actors. The crime scene was set up in exactly the same way for each participating SoCO. The scenario led to 31 actual crime scene-related DNA traces that were either victim related or traces that were handled, touched or left by the offenders:

- Outside: door keys [1], door knob [2], garbage can handles [3], balaclava [4].
- Hallway: blood on bathroom door [5], drugs in a bag [6].
- Bedroom: 3 blood swipes [7-9], small piece of duct tape for mouth [10], large piece of duct tape for hands [11], roll of tape [12], 2 latex gloves [13, 14], zip tie [15], safe with key [16], and digit wheel [17], wallet [18], handles drawer [19].
- Bathroom: bloodstain on the tap [20], blood in the sink [21].

- Living room/kitchen: money in a can [22], toolbox [thrown on the floor by offender] [23], broken kitchen shelf [24], money box with key in cupboard [25], cupboard handle [26], 2 speaker fronts torn off [27, 28], drawer handles [29].
- From the victim [collected by a colleague in the hospital]: nail dirt [30], clothes [31].

There were also 15 additional non crime scene-related DNA items intentionally placed on every mock crime scene:

- Bedroom: earring in the bed [1].
- Living room: 2 empty beer bottles on the counter [2, 3], pair of sun glasses [4], blood on dishcloth [5], empty can [6] and 2 water bottles [7, 8] in the waste bin, mobile phone [9], laptop [10].
- Outside: 4 cigarette ends [11-14], breath mark on the bedroom window [15].

*Experimental conditions*
To examine the effect of a Rapid DNA analysis opportunity on the collection, selection and analysis of DNA traces, two experimental conditions were conducted:

1. Rapid DNA - SoCOs in the Rapid DNA group had the opportunity to make use of Rapid DNA analysis through the presence of a mobile DNA lab.
2. Control - SoCOs in the control group performed their crime scene work under standard conditions.

*Mobile laboratory*
In the Rapid DNA condition a mobile laboratory was present at the crime scene to perform Rapid DNA analysis. When the SoCOs decided to perform Rapid DNA analysis on a trace, the trace was immediately handed over to the mobile laboratory. The mobile DNA lab worker received the traces for Rapid analysis, performed the tests, and handed back the results to the SoCOs.

*Boxes*
With this study we wanted to find out: on what grounds the SoCOs collect specific traces, why they think these traces could be important for the investigation, and what follow-up steps they want to take with regards to those traces. To gain insight into these aspects, SoCOs had to explain their decisions and place the trace in one of the following boxes:

- Storage - no direct follow-up on the trace, but collected for possible future analysis

- Police Laboratory - trace will be analysed in the police laboratory at the police department (not suitable for DNA)
- Forensic Laboratory - trace will be sent to the Forensic Laboratory for analysis
- Rapid DNA analysis - trace is immediately handed over to the mobile laboratory for Rapid DNA analysis

These boxes were present outside the crime scene where the SoCOs could create their working space. The Rapid DNA analysis box was only present when the participant was assigned to the Rapid DNA condition.

*CSI-trainee*
The trainee was introduced to the SoCO as a Forensic Science student who wants to learn about crime scene investigation and will join the SoCO at the crime scene. The purpose of the trainee was to understand the actions and decisions of the SoCOs and also to assist the SoCO in their administration during the investigation. The trainee did not influence the SoCOs in their work or decisions. Most SoCOs are used to having an intern at the crime scene.

*Police officer*
At the crime scene a police officer was present, played by another member of the research team. She guarded the crime scene while the SoCO performed the investigation; this is standard procedure in the Netherlands. Any questions or requests concerning the crime scene investigation could be asked to the police officer, as she was in direct contact with the SoCO in the hospital, the tactical officer involved in this case and the mobile laboratory worker.

*Participants*
A total of 40 certified SoCOs participated in this study and were evenly distributed over the two experimental conditions, thereby correcting for possible background variables like age, gender, education level and years of experience. The control group consisted of 16 males and 4 females with a mean age of 44 years (st.dev = 10.7) and a mean of 9 years (st.dev = 6.8) experience in crime scene investigation. The Rapid DNA group consisted of 17 males and 3 females with a mean age of 42 years (st.dev = 10.3) and a mean of 9 years (st.dev = 9.9) experience in crime scene investigation.

### 6.2.2 Procedure and Data Collection

Every participant followed a strict routine to collect data in the experimental study. Figure 2 illustrates this process and is further outlined in the following paragraphs.

*1) Prior to mock CSI*

Before attending the mock crime scene all participants were first welcomed and briefed by one of the researchers. Participants had to sign an informed consent form about using the results and it was made clear to the participants that this study was not a test and that their performance would not be measured. It was shared that the purpose of this study was to learn and understand the decisions that SoCOs make during an investigation. The participants were asked to operate and proceed through the investigation just like they would normally do at an actual crime scene, and they were told that the investigation would take approximately 2 to 3 hours. To understand the decisions made on securing and analysing traces it was explained that each collected trace had to be placed directly in one of the four present boxes and the role of the CSI trainee and the police officer was also established.

In addition, the Rapid DNA group received information on the option of Rapid DNA analysis. It was explained that participants could immediately decide to analyse traces rapidly at the crime scene at any desired moment by using the mobile Rapid DNA device present in the mobile laboratory. It was made clear that the participants were the decision-makers for analysing the trace. The lab worker would only handle/swab the trace, insert the swab in the system, and hand back the results. Participants were told that there was no minimum or maximum number of traces that could be analysed at once and that the technique was non-destructive in this experiment. The DNA traces were first fictitiously analysed with an indicative DNA test, given a negative result to mean there was not enough DNA to generate a profile, and was handed back after 5 minutes. With a positive result, where enough DNA to generate a profile was present, the trace was analysed with the Rapid DNA technology. In that case, the results and the trace would be handed back after 30 minutes.

When there were no further questions about the set-up, the study started and the first information segment about the crime scene was given through the ‘emergency call centre’.

*2) During mock CSI*

When entering the mock crime scene, the real-life experiment started and the participants performed their crime scene investigation. During the investigation the participants were observed, and data was collected on the collection, selection, and analysis decisions of the handled traces through the observation of the participant and the interaction with the trainee. When finishing up the investigation the participants were asked to write down their scenario of what happened, and any additional data that was collected.

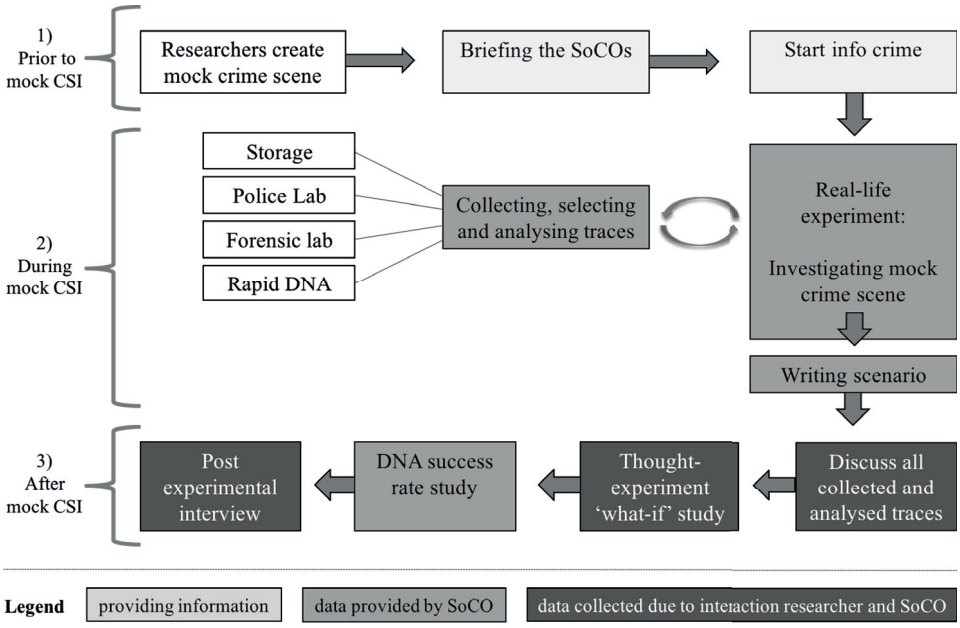


**Figure 2.** Experimental Procedure and Data Collection

*3) After mock CSI*

After finishing the mock crime scene investigation, data was collected through four steps - mostly through direct interaction with the researcher.

Initially, the boxes in which the participants assigned the traces during the study were placed on the table. The participants were asked to explain the considerations underlying their decisions to deal with traces in a specific way. They also had to explain the possible function of the traces in the subsequent investigation process.

Then secondly, participants were asked to participate in a 'thought experiment', where they had to deal with a 'what-if' situation. For this experiment, all traces that were collected by the participants were in the middle of the table, and the participants were asked to reassign them into the different boxes again (storage, Police Lab, Forensic Lab, and, if applicable, Rapid DNA analysis).

- Participants in the *control* group now performed the study as if they had a Rapid DNA device at hand. The Rapid DNA device was explained in the exact same way as was done for the Rapid DNA group during the briefing of the mock crime scene investigation. Based on this additional information the 'Rapid DNA analysis' box was added on the table and the participants were asked to reassign the traces as if they performed the mock crime scene investigation with a mobile laboratory at hand.

- Participants in the *Rapid DNA* group were asked to reassign the traces as if they performed the mock crime scene investigation under standard conditions. They had to decide how they would have dealt with the collected traces if they had done the investigation under 'normal' circumstances, without a Rapid DNA device. The 'Rapid DNA analysis' box was taken away from the table and the participants were asked to forget that they had this opportunity, including the knowledge they had obtained through these rapid analyses.

In the third step of the post mock CSI procedure, the participants conducted a DNA success rate study. Laboratory DNA success rates are important data to allow decisions to be made on the analysis of a DNA trace. To test the knowledge of the participants on this aspect, participants had to fill out a questionnaire on DNA success rates. The participants had to assess the DNA success rates, the expected chance of obtaining a DNA profile suitable for comparison, of all traces they collected and sampled during their investigation. They had to rate these chances on a 7-point Likert scale, whose endpoints were anchored with 1 as extremely low and 7 as extremely high.
Finally, a post experimental interview was conducted where participants were asked about the way they experienced the mock crime scene investigation, their performance, and the Rapid DNA technology was discussed.

## 6.3 Results

Firstly, a quantitative analysis was performed to examine the influence of a Rapid DNA analysis option on the collection of traces and the selection of traces for analysis. The software SPSS (37) was used for statistical analyses. After this, a qualitative analysis was utilised to examine the decision process for selecting DNA traces for analysis. Finally, the perspective of SoCOs regarding the DNA success rates was explored to examine DNA success rate knowledge.

### 6.3.1 DNA Traces Collected During Real-life Experiment

In total, 63 different types of DNA traces were collected by at least one of the SoCOs, whereas our scenario led to a total of 31 crime related and 15 non-crime related DNA traces. This means that the SoCOs identified 17 additional items or samples as DNA traces that we did not consider as crime related or were intentionally placed at the crime scene. These traces were, based on our scenario, non-crime related traces.
Participants in the control group collected, on average, 25 different types of DNA traces (st.dev = 5.2), and the Rapid DNA group 22 (st.dev = 4.3). We performed an independent sample *t*-test and found no differences between the two groups in collecting DNA traces in general ($t(38) = 1.58$, $p = 0.122$).

From these 63 different types of DNA traces, 39 were selected for DNA analysis by at least one SoCO. In our further data analyses, we only focus on the traces that were collected and analysed at least once. Figure 3 shows these 39 DNA traces and the results that were given back to the SoCOs when tested with a Rapid DNA device. These 39 DNA traces were further classified into 4 categories: blood (n=7), saliva (n=9), contact (n=18) and interdisciplinary (n=5) traces as shown in Table 1. Interdisciplinary traces are traces that can be sampled for multiple analyses on the same spot, for instance analysing possible fingerprints on a piece of tape or swabbing the prints on the tape for DNA analysis.

Most of these collected and analysed DNA traces concerned the intentional crime related traces as based on our scenario. In addition, the non-crime related DNA traces towel, coffee cup, breakfast knife and plate, were also collected and analysed at least once by a SoCO.

Figure 3 shows that 64% (25/39) of the collected and analysed traces were in fact crime related and 84% of those crime related traces were also offender related (21/25).

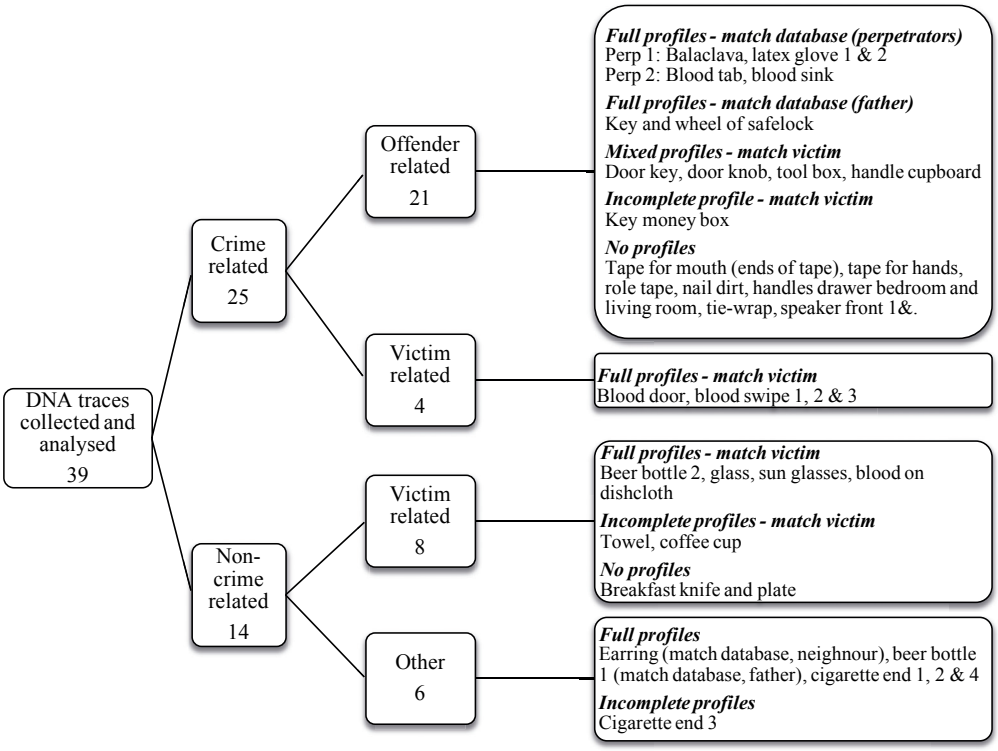


**Figure 3**. Rapid Analysis Results of all DNA Traces that were sent in at least once for Analysis either at the Laboratory or Rapidly

**Table 1.** The Analysed DNA Traces were Classified in 4 Categories (based on the trace type)

| Trace Type Category | Trace Items / Samples |
|---|---|
| Blood (n= 7) | Blood tap, blood sink, blood door, blood swipes (1-3) and blood on dishcloth |
| Saliva (n= 9) | Balaclava, beer bottles (1 & 2), glass, coffee cup and cigarette ends (1-4) |
| Contact (n =18) | Latex gloves (1 & 2), key and wheel of safe, door key, door knob, tool box, cupboard handle, key of money box, nail dirt, drawer handles (bedroom and living room), zip tie, sun glasses, towel, breakfast knife and plate, and earing |
| Interdisciplinary (n= 5) | Tape for mouth (ends of tape), tape for hands, roll of tape and speaker fronts (1 & 2) |

Concerning the 39 collected traces that were analysed at least once; there was again no difference in the total number of DNA traces collected when performing an independent sample *t*-test and (Table 2). However, Table 2 indicates that participants in the control group collected significantly more blood traces ($t(38) = 2.09$, $p = 0.043$) compared to the participants in the Rapid DNA group. When studying these blood type traces in more detail, the difference in collecting the blood on the dishcloth stands out. This trace was collected by 9 participants in the control group but by only 1 participant in the Rapid DNA group. For the other blood traces there were no systematic differences between the groups.

**Table 2.** Mean Number of DNA Traces Collected with *(st.dev),* by Participants in the Rapid DNA Group (N=20) and the Control group (N=20)
The p-value shows the results of an independent *t*-test

| Trace Type | Rapid DNA group | Control group | p-value |
|---|---|---|---|
| Blood (n=7) | 4 *(1.7)* | 5 *(0.8)* | ***0.043*,*** $t(38) = 2.09$ |
| Saliva (n=9) | 7 *(1.4)* | 7 *(1.8)* | 0.770**,** $t(38) = 0.30$ |
| Contact (n=18) | 6 *(2.5)* | 7 *(2.1)* | 0.631**,** $t(38) = 0.49$ |
| Interdisciplinary (n=5) | 4 *(1.0)* | 3 *(0.9)* | 0.505**,** $t(38) = -0.67$ |
| *Overall (N=39)* | *21* | *22* | *0.358, t(38) = 0.93* |

** Significant difference between numbers of traces collected in the Rapid DNA condition and in the control condition.*

### 6.3.2 Collected vs. Analysed DNA Traces in General

Whilst conducting this study, the question was raised as to whether the number of traces analysed is dependent on the number of traces collected by the participants. To test such a relationship a Pearson's r correlation coefficient test was performed. There was only one opportunity for trace collection in this study: during the real-life experiment. A positive correlation was found within the control group between the number of DNA

traces collected and the number of DNA traces analysed, r = 0.561, n = 20, p = 0.005. Within the Rapid DNA group such a correlation was not observed.

### 6.3.3 DNA Traces Selected for Analysis

*Real-life experiment*

During the real-life experiment the participants in the Rapid DNA group analysed, on average, significantly more DNA traces than the participants in the control group ($t(38) = -2.89$, $p = 0.006$). In the control group the participants decided to analyse, on average, 8 DNA traces (st.dev = 3.4) at the laboratory. The participants in the Rapid DNA group decided to analyse, on average, a total of 12 DNA traces (st.dev. = 4.6), of which 9 were with the Rapid DNA device and 3 at the laboratory (Table 3 & Figure 4, ***bar 1 & 2***).

When considering these analysed traces in more detail, Table 3 further shows that the Rapid DNA group analysed significantly more blood, saliva, and contact traces when compared to the control group. On average, the participants in the Rapid DNA group showed a similar pattern of deciding to analyse samples with the mobile Rapid DNA device as the participants in the control group decided for analysis at the laboratory. However, the participants in the Rapid DNA group chose to analyse on average 1 extra sample in each trace category at the laboratory.

When studying the analysed traces on trace type level, it is observed that for the traces in the blood category the participants in the Rapid DNA group decided to analyse more often the traces *blood on the door*, *blood in the sink* and additional *blood swipes*. In the saliva category, more *cigarette ends* and *beer bottles* were analysed in the Rapid DNA group. Within the contact category, especially more *infrequently collected trace* samples were analysed in the Rapid DNA group. In addition, the traces *door keys* and *wheel of safe lock* were solely analysed in this rapid condition. Participants of the

**Table 3.** Mean Number of DNA traces Analysed with *(st.dev.),* by Participants in the Rapid DNA Group (N=20) and the Control Group (N=20)
The p-value shows the results of an independent *t*-test

| Trace Type | Rapid DNA Group | | | Control Group | p-value |
|---|---|---|---|---|---|
| | Rapid | Lab | Analysis (tot.) | Lab | |
| Blood (n=7) | 2 *(1.7)* | 1 *(1.3)* | 3 *(1.7)* | 1 *(1.5)* | 0.033*, $t(38) = -2.22$ |
| Saliva (n=9) | 2 *(2.0)* | 1 *(1.5)* | 3 *(2.1)* | 2 *(1.6)* | 0.027*, $t(38) = -2.30$ |
| Contact (n=18) | 3 *(2.4)* | 1 *(0.8)* | 4 *(2.0)* | 3 *(1.2)* | 0.038*, $t(38) = -2.17$ |
| Interdisciplinary (n=5) | 2 *(1.7)* | 1 *(1.2)* | 2 *(1.4)* | 2 *(1.0)* | 0.800, $t(38) = -0.26$ |
| Overall (N=39) | 9 *(5.4)* | 3[1] *(3.3)* | 12 *(4.6)* | 8 *(3.4)* | 0.006*, $t(38) = -2.89$ |

[1]*Due to rounding off the numbers do not add up.*
**Significant difference between the numbers of traces analysed in the rapid condition (Analysis total) and in the control condition (Lab).*

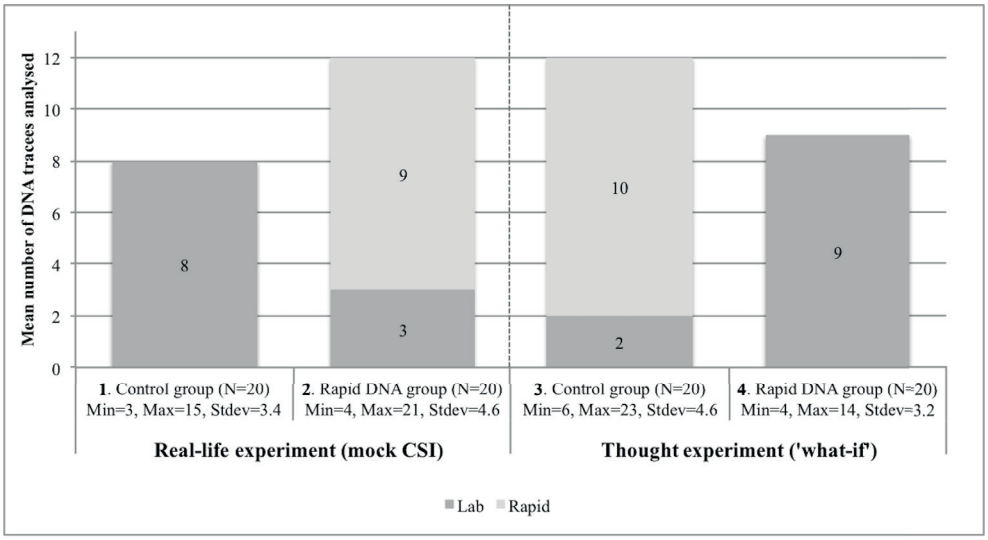


**Figure 4.** Mean Number of DNA Traces Analysed with Rapid DNA or at the Laboratory during the Real-life and the Thought Experiment

Rapid DNA group who decided to analyse these discussed traces, mostly decided to analyse them with the mobile Rapid DNA device.

The two groups showed no overall difference in their decisions concerning the traces in the interdisciplinary category. However, it was noted that only the participants of the Rapid DNA group decided to analyse the *speaker traces*, and always with rapid analysis. Finally, participants in the control group and the Rapid DNA group did not differ from each other concerning the need to analyse most of the traces left or handled by the perpetrator including *blood tap, balaclava*, *gloves*, *zip tie*, *keys for money box*, *tape for mouth*, *tape for hands* and *roll of tape.* These traces were discovered and analysed by most of the participants*,* except for the blood on the tap, which was only discovered by 9 of the 40 participants and analysed by 8 of them. This was interesting because this trace could only lead to the second offender. Again, the Rapid DNA group decided to analyse most of these important perpetrator-related traces rapidly.

*Thought experiment*

During the thought experiment, the control group had a Rapid DNA option, whereas the Rapid DNA group lost this option and had to process the traces under standard conditions. The decisions the participants made on the analysis of traces during the thought experiment showed the same trends as observed during the real-life experiment. Participants in the Rapid DNA group now decided to analyse on average 9 DNA traces, whereas participants in the control group chose to analyse 12 DNA traces of which 10 with the Rapid DNA device and 2 at the laboratory (Figure 4, *bar **3 x 4**).* Although this difference is not significant ($t(38) = 2.008$, $p = 0.052$) the p-value, together with the

results shown in Figure 4, indicate there is reason to suggest a similar trend of deciding to analyse DNA traces when Rapid DNA is at hand, as was observed in the real-life experiment.

*Real-life experiment vs. thought experiment*

Each participant actually performed two experiments when deciding on DNA analysis in this study. They made decisions in a standard procedure condition as well as in a Rapid DNA option condition. The Rapid DNA option was given to them either during the real-life experiment or during the thought experiment. A more valuable analysis, therefore, is combing the DNA analysis decisions of both experiments and conducting a mixed-design ANOVA, where the availability of the Rapid DNA option is a between-group as well as a within-group variable. The results show a strong significant interaction regarding the total number of DNA traces analysed depending on the availability of the Rapid DNA device (Figure 5). Both during the real-life experiment as well as during the thought experiment, participants analysed more DNA traces when they could use a Rapid DNA analysis device. This means that the total analysis of DNA traces, with and without Rapid DNA option, was significantly different for participants in the control and Rapid DNA group *(*$F(1,38) = 25.57$, $p < 0.001$). Both in the Rapid DNA group and in the control group, participants analysed significantly more DNA traces when Rapid DNA was an option compared to a standard protocol condition.

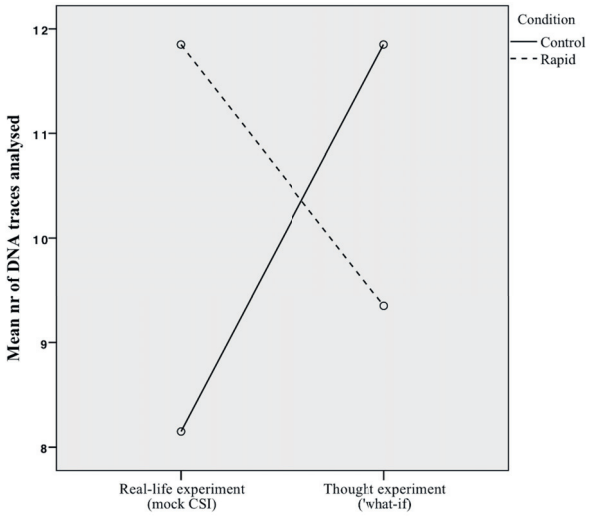


**Figure 5.** Mean Number of DNA Traces Analysed by Participants in the Control and Rapid DNA Group during the Real-life and Thought Experiment Showing a Significant Interaction Effect (mixed-design ANOVA $p < 0.001$)

### 6.3.4 Qualitative Analysis - Decision Process to Select DNA Traces for Analysis or Storage

To explore the reasons underlying the decisions of the participants to select DNA traces for analysis or to keep them in storage, we gathered qualitative data through intensively discussing the traces participants collected and analysed during the 'real-life' experiment of performing the mock CSI (Figure 2) after the experiment was finished. For this purpose, these decisions were manually analysed, taking the following most often mentioned factors into consideration: 'crime relatedness', 'perpetrator relatedness', 'victim relatedness', 'DNA success rates', 'multidisciplinary research required', 'additional information concerning the case required', 'important trace', 'less important trace, others more valuable', 'scenario testing / reconstruction', 'because it is an option', 'no rush', and 'depending on capacity'.

*Reasons to analyse DNA traces*

Table 4 shows the qualitative results of the aforementioned reasons underlying the decision to analyse a DNA trace. In general, either with or without the option of Rapid DNA analysis, the main reason to analyse a trace was because it was considered perpetrator related. This was often mentioned by the participants as: *"This is a perpetrator trace"* or *"This is an important trace and could lead to the perpetrator"*. Especially for the blood traces, victim relatedness (87%) appeared to be correlated with perpetrator relatedness (83%) as a reason to rapidly analyse the specific trace: *"The victim was hurt, but maybe the perpetrator got wounded too and left the blood trace"*. The next main reason for rapid analysis of blood traces, mentioned in 30% of the cases, was simply because it was possible: *"If there is the opportunity of rapid analysis, why not use it?"* For saliva (11%), contact (13%) and interdisciplinary (7%) traces this reason was mentioned far less.

**Table 4.** Reasons Mentioned by the Participants in a given Category to *Select and Analyse* a DNA Trace (in percentages).
The numbers represent in what percentage of the decisions made in a specific category the underlying reason was mentioned. For example: the reason 'perpetrator relatedness' was mentioned in 53% of the blood traces that went for laboratory analysis in the Rapid DNA group (n= 15).

| Category | Group | Analysis | Perp. related | Vict. related | Multi-discipl. | More info | Success rate | Less impor. | Crime related | Scena-rio | Possi-ble | No rush | Impor-tant | Ca-pacity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Blood | Rapid | Lab (n=15) | 53 | 73 | 0 | 7 | 7 | 20 | 13 | 0 | 0 | 40 | 0 | 0 |
| | | Rapid (n=23 | 83 | 87 | 0 | 4 | 22 | 13 | 4 | 9 | 30 | 0 | 0 | 4 |
| | Cont. | Lab (n=23) | 74 | 74 | 0 | 9 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Saliva | Rapid | Lab (n=5) | 80 | 20 | 20 | 40 | 0 | 40 | 0 | 40 | 0 | 20 | 0 | 0 |
| | | Rapid (n=28) | 71 | 14 | 0 | 11 | 4 | 0 | 11 | 0 | 11 | 0 | 7 | 0 |
| | Cont. | Lab (n=21) | 86 | 19 | 5 | 29 | 0 | 0 | 14 | 5 | 0 | 0 | 5 | 0 |
| Contact | Rapid | Lab (n=12) | 25 | 42 | 0 | 8 | 25 | 17 | 8 | 17 | 8 | 0 | 0 | 8 |
| | | Rapid (n=54) | 81 | 15 | 2 | 7 | 26 | 0 | 17 | 7 | 13 | 0 | 15 | 0 |
| | Cont. | Lab (n=40) | 73 | 18 | 5 | 0 | 25 | 0 | 10 | 8 | 0 | 0 | 10 | 0 |
| Inter-disciplinary | Rapid | Lab (n=17) | 18 | 6 | 94 | 12 | 6 | 29 | 0 | 0 | 6 | 12 | 6 | 0 |
| | | Rapid (n=28) | 64 | 0 | 25 | 7 | 11 | 7 | 18 | 0 | 7 | 0 | 14 | 4 |
| | Cont. | Lab (n=45) | 69 | 53 | 76 | 16 | 11 | 0 | 16 | 7 | 0 | 0 | 0 | 2 |

To analyse traces at the *laboratory*, the participants in the Rapid DNA group also stated perpetrator relatedness as a reason to analyse blood (53%), saliva (80%) and contact traces (25%). The main arguments mentioned not to analyse those types of traces rapidly, but at the laboratory, were the victim relatedness of the blood (73%), saliva (20%) and contact traces (42%), often in combination with considering those traces to be of less importance and therefore 'no rush' for rapid analysis, for instance: *"The perpetrator could also be wounded, but I think the trace is left by the victim. No rapid analysis because it is probably the victim's, you do not need to know this fast."* or *"I consider this trace of not enough priority for rapid analysis. I do want the trace to be analysed but with regular laboratory analysis is fine."*
The main reason for the interdisciplinary traces to go for laboratory analysis and not rapid analysis was because they considered these traces to have multidisciplinary analysis options (mentioned in 94% of these cases) and therefore should be analysed at the laboratory: *"It is a multidisciplinary trace, possible for DNA, fingerprint, 'souche' and fibre analysis. This needs to be analysed under optimal circumstances and therefore analysed at the laboratory and not rapidly."* Although more than half of the analysed interdisciplinary traces (28/45) still went for rapid analysis in the Rapid DNA group; the multidisciplinary nature of these traces was then only specified in 7 of those 28 (25%) cases. Again perpetrator relatedness was of highest importance to decide for rapid analysis of those interdisciplinary traces.
In general DNA success rates were not taken into account as often as was expected, it was only mentioned in 14 % of the cases when deciding for DNA analysis on a trace. For instance: *"For Rapid analysis because I think this is a perpetrator related trace, and I know that latex gloves show very good DNA results"*. DNA success rates were mostly mentioned for traces in the contact (26%) and blood (22%) categories and were hardly ever mentioned in the saliva (4%) category. However, when it was considered it was merely used as a reason to analyse the trace.

*Reasons to keep the DNA traces in storages*
Success rates were rarely stated as a reason *not* to analyse a trace. For participants both in the Rapid DNA as well as the control group the main reason to decide *not* to analyse a trace and keep it in storage as a reserve was because more information about the criminal case was desirable (Table 5). Even though perpetrator relatedness was again often specified, it was mainly mentioned to wait for the statement of the victim before deciding to analyse the trace, for instance: *"Based on the traces at the crime scene there is a story of what could have happened on the scene. However, you need to be careful in making conclusions, more options could be possible, this depends on the statement of the victim."* However, the necessity for additional information concerning the case was also mentioned a few times when the participants still decided to analyse the trace (Table

4). The main reason not to wait for additional information was again perpetrator relatedness of the trace.

When deciding *not* to analyse a trace, but keep the trace in storage, the victim relatedness of the trace was an important reason. Stored traces were considered more often as 'less important' than traces that actually went for analysis: *"For the time being I consider this a victim related trace, I know that the victim is wounded but I don't know if the perpetrator got wounded. I have other more important perpetrator related traces for analysis."* Especially for the interdisciplinary traces participants also often discussed the capacity as a reason not to analyse the trace at this moment: *"Not all collected traces can be analysed, you always have to make choices"*.

Lastly, it was observed that for saliva traces collected from drinking items an additional reason was considered, namely the hypothesis that the perpetrator and the victim were acquaintances of each other. This was merely mentioned as a reason not to analyse saliva traces, for instance: *"There were 2 beer bottles on the counter. It could be that the victim invited a friend over for a beer. It could also be that this friend decided to rob him. There are different scenarios for the beer bottles, we have to wait for the statement of the victim"*.

**Table 5.** Reasons Mentioned by the Participants in a given Category to keep a DNA Trace in *Storage* (in percentages).
The numbers represent in what percentage of the decisions made in a specific category the underlying reason was mentioned. For example: the reason 'more info is necessary' was mentioned in 26% of the blood traces that were decided to keep in storage in the Rapid DNA group (n= 19).

| Category | Group | Perp. related | More info | Vict. related | Less impor. | Ca-pacity | Acquain-tances | Multi-discipl. |
|---|---|---|---|---|---|---|---|---|
| Blood | Rapid (n=19) | 42 | 26 | 53 | 11 | 5 | 0 | 0 |
| | Cont. (n=32) | 59 | 50 | 69 | 9 | 6 | 0 | 0 |
| Saliva | Rapid (n=31) | 42 | 61 | 35 | 23 | 10 | 45 | 0 |
| | Cont. (n=48) | 42 | 63 | 21 | 6 | 10 | 42 | 0 |
| Contact | Rapid (n=50) | 62 | 52 | 16 | 12 | 0 | 0 | 0 |
| | Cont. (n=71) | 66 | 59 | 28 | 24 | 7 | 6 | 0 |
| Inter-disciplinary | Rapid (n=18) | 44 | 44 | 22 | 28 | 28 | 0 | 17 |
| | Cont. (n=18) | 78 | 72 | 39 | 44 | 50 | 0 | 28 |

### 6.3.5 DNA Success Rates

The participants assessed the expected DNA success rate of obtaining a profile of their collected DNA traces on a 7-point Likert scale. This scale was further categorised to: 1-2 = low, 3-5 = moderate, and 6-7 = high chance of obtaining a profile. The expected success rates for obtaining a DNA profile, as rated by the participants, were then compared to the actual DNA success rates (38). There were no differences between the control and the Rapid DNA group in rating success chances of their collected traces. Therefore, the ratings on success chances of the DNA traces from both groups could be

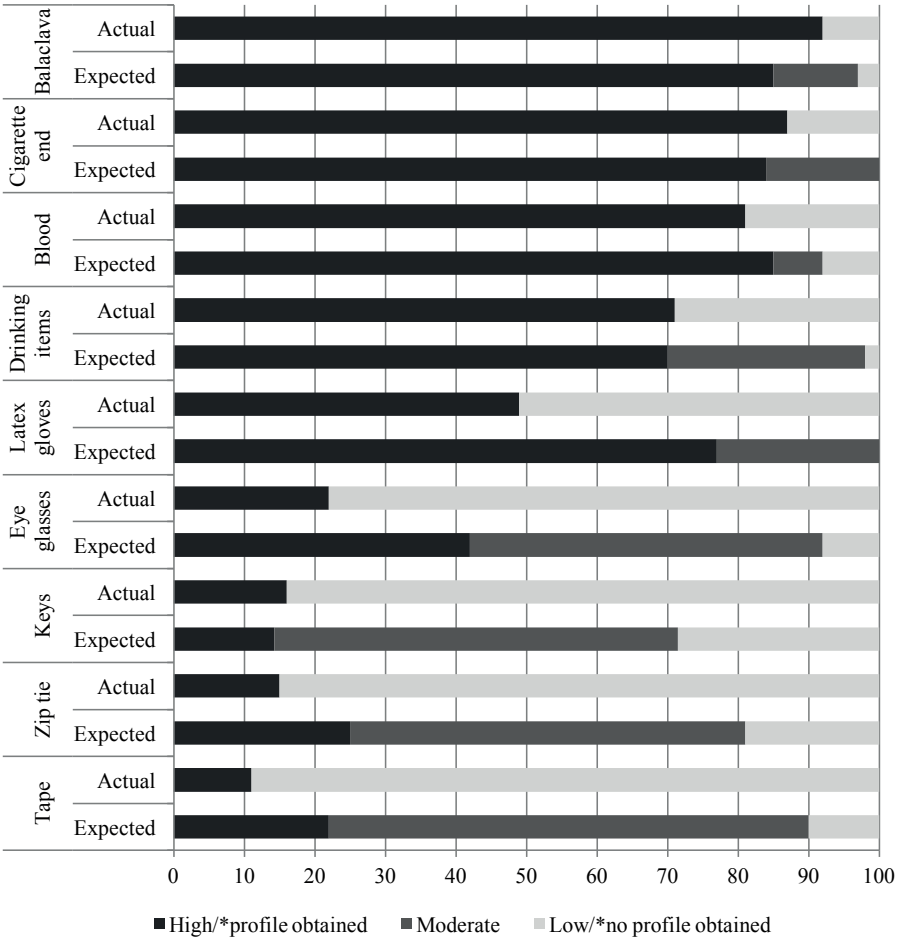


**Figure 7[2].** Expected DNA success rates to obtain a profile versus the actual success rates (38), ranked from highest to lowest *actual* success rates .
The *actual* success rate scale shows the probability of obtaining (any kind of) DNA profile or no profile. The *expected* success rate scale shows the percentage of participants rating the trace on a 7-point Likert scale, we consider 1-2 as low, 3-5 as moderate and 6-7 as high.

taken together for further analysis. The rated success chances were compared to actual success rates (38), these actual success rates were unknown to the SoCOs during this study.

Figure 7 shows that for the more successful traces (*blood*, *cigarette ends*, *balaclava* and *drinking items)* the majority of the participants were able to correctly rate the success chance of these traces. However, with the less successful traces, (*latex gloves*, *glasses*, *keys*, *zip tie* and *tape)* rating success chances became more difficult. For instance, the *zip tie* was rated by 25% of the participants as highly successful and in 56% as

[2] A comparable study on DNA success rates was performed with NYPD SoCOs (40)

moderately successful in obtaining a profile, whereas the actual success rate is only 15%. The perspective of SoCOs on obtaining profiles for these traces appears to be much higher than is actually the case. This could clarify why Rapid DNA analysis was also often used for contact and interdisciplinary traces.

## 6.4 Discussion

This mock crime scene study showed overall that Rapid DNA analysis did not influence the collection of traces, resulted in a higher throughput of traces for DNA analysis, and also led to faster identification of the suspect. In general, it can be concluded that a criminal case might be solved more quickly when introducing this Rapid DNA technology.

Overall, the control group and the Rapid DNA group collected the same number of DNA traces and similar kinds of DNA traces. This indicates that there is no influence on the process of detecting relevant physical traces with the potential use of a Rapid DNA technology. This was also acknowledged in a previous publication on this mock crime scene scenario where it was argued that the SoCOs were not directed in their search to detect traces by these new technologies (25), which is a reassuring finding. It suggests that the possibility of Rapid DNA analysis does not lead to either missing important DNA traces or focusing too much on finding DNA traces. For instance, although few SoCOs collected the incriminating blood trace on the tap in the bathroom (7 times in total), there was no difference between the Rapid DNA and the control group in this respect. However, when categorising on trace type level (blood, saliva, contact, interdisciplinary) it was found that the control group collected significantly more blood traces compared to the Rapid DNA group. This difference can possibly be explained by the fact that more SoCOs detected and collected the blood on the dishcloth in the control group (9 times) compared to the Rapid DNA group (1 time). Because this difference was only observed with one trace, that was considered an old and not crime related trace, it is difficult to explain these differences. On the one hand this could indicate an influence of Rapid DNA analysis on missing DNA traces, or on the other hand, it might be that the participants in the Rapid DNA group are more focused on crime related traces and can therefore better discriminate between crime related and non-crime related traces. However, the higher number of blood traces collected by the control group did not result in more analysis of blood traces. In fact, the Rapid DNA group analysed significantly more blood samples.

The decision to analyse a DNA trace appeared to be independent of the number of DNA traces collected, when Rapid DNA analysis was an option. Within the control group, however, a positive correlation was observed between the number of traces collected and the number of traces analysed. Again, this indicates an effect of Rapid DNA

analysis; with Rapid DNA at hand more analyses are performed, independent of the number of traces collected.

Overall, the Rapid DNA group analysed significantly more DNA traces than the control group during the real-life experiment. A reason for this might be that the results of one piece of evidence could influence the interpretation of another piece of evidence, in such a way that the second piece of evidence is evaluated in the same manner as the first piece of evidence (39). When Rapid DNA is at hand results could be obtained more quickly, and thus might lead to a form of confirmation bias on a second piece of evidence. Another phenomenon that could lead to a form of confirmation bias is the urge to believe and confirm that the offender left the trace when immediate DNA analysis led to a rapid database hit.

Another explanation for the higher number of traces analysed when Rapid DNA is an option could be that the Rapid DNA group can focus directly on identifying a suspect as well as reconstructing a crime scene; they can have immediate feedback on the traces, and might be more inclined to also analyse expected victim related traces. Thus, considering analysis both for the source as well as for reconstruction purposes. In the control group, on the other hand, participants are not able to receive fast feedback and therefore prioritise identifying the unknown perpetrator. Focusing on reconstruction comes in a later stage.

Interestingly, the same trend for deciding to analyse traces was observed during the thought experiment, even though the control participants did not receive the rapid result in this experiment. A significant interaction of total DNA traces analysed was found, caused by the availability (either in the real life experiment or in the thought experiment) of a Rapid DNA analysis device. Both in the rapid as well as the control group, participants analysed more DNA traces with a Rapid DNA option than without this option, during both the real-life experiment and the thought experiment. This strongly indicates that having the option for Rapid DNA analysis on the crime scene results in analysing more DNA traces, irrespective of immediately receiving the results or not.

When taking into account the fact that the traces were analysed just as often within the control as the Rapid DNA group during the real-life experiment, at least one perpetrator would be identified. However, in addition the Rapid DNA group analysed many more DNA traces. This was not to test a possible scenario of two perpetrators; 10% of the participants in the control group mentioned the possibility of two perpetrators in their scenario and this was only in 5% of the Rapid DNA group (see also (29)). In particular, more victims related traces were analysed in the Rapid DNA group, suggesting that with Rapid DNA analysis at hand, SoCOs are also focusing on reconstruction; finding out what happened vs. finding out who is the suspect. Without the rapid option the SoCOs might feel more restricted in analysing DNA traces, because they remain ignorant of the results of these analyses and therefore focus more on identifying the perpetrator in the first stage of the analysis procedure.

In the Netherlands there is a maximum capacity of DNA traces that can be sent to the laboratory for analysis. This restriction could have influenced the decision-making process of the participants in the control condition who had to work with standard protocols. Furthermore, this analysis restriction could also have influenced the Rapid DNA condition. In this case participants might have been inclined to analyse more DNA traces because, due to the Rapid DNA option, they believed to have more capacity for analysis. Restrictions for analysis were not specified or corrected in the experimental study and could therefore have influenced the results, which might be a limitation of the set-up.

Overall, the main reason not to analyse a trace, and to keep it stored, was to wait for the statement of the victim and to gain more information on traces. Although it was often mentioned that more information was desirable, many traces in the Rapid DNA condition were still analysed, this was especially found for traces in the saliva group. Possibly SoCOs decided to use rapid analysis not because they considered it immediately necessary but because it is available with this 'new and exciting' technology, but it is also possible that they used this technique because it can promptly lead to new investigative information. The time factor therefore plays a different role in the two conditions. Participants in the control group have to wait days, weeks or even months for DNA results. Therefore, waiting a (few) days on the statement of the victim is less significant in their DNA trace prioritisation and selection process compared to participants in the rapid group who can receive DNA results within 30 minutes. All participants collected, selected and analysed at least the balaclava trace or the glove trace, resulting in identifying one perpetrator. In this case, it could have saved a lot of time and money when the participants were waiting to complete any additional analysis until the statements of the victim and the identified suspect. However, it is obviously difficult to anticipate strategically on information opportunities that occur during the subsequent information process. SoCOs have to make decisions in light of the criminal case by weighing the best options for analysing traces. Obtaining rapid feedback on the analysed traces can guide the decision-making process of the SoCO for further analysis of traces but can also affect the progress of the entire criminal investigation. To ensure that SoCOs make strategic and well thought out decisions in this new process with Rapid DNA, it is important to assist them in their trace prioritisation and selection process.

When looking more into the different types of DNA traces analysed, the participants in the Rapid DNA condition analysed a great variety of DNA traces rapidly, including minimal contact traces and interdisciplinary traces. It was expected that the SoCOs would especially use the Rapid DNA technology for 'routine' analysis of blood and saliva type traces, and would also consider success rates to distinguish between traces before deciding to use rapid analysis. The qualitative data revealed that DNA success rates are rarely taken into account before making a decision. In addition, the analysis of the DNA success rates showed that SoCOs are unaware of actual DNA success rates.

Especially for less successful traces, mainly the contact and interdisciplinary trace items, success was rated much higher than the actual success figure. This might explain why various types of traces were analysed with this Rapid DNA technology. This indicates that knowledge on actual evidence-based DNA success rates is necessary information for the decision-making process of Rapid DNA analysis.

In this study, SoCOs were given very little information about the Rapid DNA technology because we wanted to direct them as little as possible and wanted to learn the effects if the police force decided to simply start using this technology. Even though the SoCOs had the opportunity to ask questions during the briefing and the experiment, none of the participants asked about DNA success rates or the sensitivity of the technology.

Not only are current Rapid DNA technologies less sensitive than laboratory DNA technologies, they also lack the opportunity to save part of the sample and therefore analysing a sample with a Rapid DNA technology should be considered destructive. The destructive nature of the technology was not mentioned in this study, which could be considered a limitation; however, SoCOs in the Rapid DNA group rarely decided on further analysis at the laboratory after a negative outcome. A negative outcome could therefore negatively influence their further decisions on analysing the traces. This again shows that knowledge of DNA success rates, especially Rapid DNA success rates, is essential for optimal decisions. It is important to realise that the impact of rapid analysis can differ between types of cases and traces. But also the effect of other rapid identification technologies could influence the Rapid DNA analysis decisions, such as rapid fingerprint analysis. However, we do not expect such technologies to greatly impact the results of this study as DNA and fingerprint analyses are very different. The SoCOs can perform fingerprint analysis themselves, which is standard procedure in current CSI practice, whereas for DNA analysis this is not the case.

Another limitation of this study was that we did this study on a ‘mock’ crime scene. Although we tried to mimic an actual case in this mock field experiment, it is still a fake case and procedures were not completely comparable to real-world practices. However, the SoCOs who participated in this study claimed that even though they performed their investigation on a mock crime scene, it did not influence their behaviour. In addition, the data showed that SoCOs in the experimental and control group acted the same way in deciding for analysis during the real-life and thought experiments, this indicates that performing an actual real-life (mock) CSI yields the same results as conducting a thought experiment. This suggests that, for further research, using less labour-intensive research methods, such as vignette studies and thought experiments could be sufficient

The objective of Rapid DNA analysis is to quickly identify a suspect and to get a fast lead in an investigation. Therefore, selecting the crime and perpetrator related trace(s) for analysis is essential, whereas analysing victim related traces might have less priority

at this time. Due to the technology being destructive for the inserted sample, and because the analysis is less sensitive than laboratory options, DNA success rates should then be addressed to better allow a decision to be made regarding Rapid DNA analysis. As such, we expected SoCOs to use some sort of framework to decide for DNA analysis. However, in their decision process crime relatedness was rarely mentioned by the SoCOs in the study; SoCOs often went straight to discussing perpetrator or victim relatedness. Although the question as to whether traces are crime related may be answered in their mind, it is important that they consciously consider the crime relatedness of a trace first, before deciding on the use of a Rapid DNA analysis.

In a previous article (using this mock crime scene), focused on scenario building with rapid identification information, it was found that SoCOs decided to analyse traces much faster, without observing the complete crime scene first when they had the opportunity to use a mobile DNA analysis device (29). The current study shows that many DNA traces were analysed, including traces that were not even crime related. In addition, SoCOs appeared to lack knowledge on DNA success rates, risking the analysis of low template DNA traces and possibly missing vital information for the investigation. A previous study showed that with the current sensitivity of the Rapid DNA technology only a few trace items could be of interest for Rapid DNA analysis (10). Therefore, the four-step decision process for DNA analysis (35), as suggested in in the introduction, seems highly necessary and could guide SoCOs in making reasoned decisions for the analysis of DNA traces. The results of this study show that this process, or framework, is rarely used to make a decision on conducting a DNA analysis in general.

With future implementation of Rapid DNA technologies crime scene procedures will need adjusting, because not only the workload of the SoCO will change, but also the decisions for analysing traces.

The worst-case scenario when using Rapid DNA analysis would be linking innocent people to a crime and not pursuing any further analysis. This could occur especially when there are several potential perpetrator related traces and only the trace with the highest success rate proceeds to analysis, resulting in identifying information. For this reason, we suggest a ‘reconsideration step’ in the Rapid DNA procedure, where all traces are to be evaluated with the investigative team and an appointed forensic scientist after the crime scene investigation, allowing a decision to be made regarding further DNA analysis. This might not rule out potential errors or biased decisions, but it could assist in a more thorough decision-making process.

Taking all this together we propose to expand the four-step procedure to a ‘hierarchy of decisions’ for Rapid DNA analysis:

1) Detect and collect all evidentiary traces
2) Rank the traces by crime relatedness
3) Rank the presumed crime related traces by perpetrator relatedness

4) Use the Rapid DNA success rate figure for further selection (Table 1 in Mapes et al., 2016 (10))
5) Select the most promising trace(s) for Rapid DNA analysis
6) Reconsider all collected traces in the light of different crime scenarios with the investigative team after the crime scene investigation
7) Decide for further DNA analysis

We expect this 'hierarchy of decisions' to highly contribute to the forensic investigative practice and to benefit the decision-making process for Rapid DNA analysis. We should also keep in mind that analysing traces is not only for the identification and location of a suspect, but also to build a case and to assist the court.

It is time for the forensic community to realise that current practices are in need of change. Designing effective new strategies and guidelines when integrating new and rapid technologies requires an understanding of the field of crime scene practice (23). This article focused mainly on the trace collection and selection process, and SoCOs' work practices when integrating a Rapid DNA technology. Research towards understanding best practices in crime scene investigation is therefore necessary. In addition, it should be kept in mind that for an optimal technology driven change, cultural (social, organisations, public) and political factors (management, roles, relationship, cost effectiveness) are also important aspects to take into account (11, 17). We hope to encourage the forensic science community to take action in these fields of analysis.

To finish, this study gives an insight into the effects of implementing a new technology within police investigation. We can conclude that an effect of integrating Rapid DNA analysis at the crime scene is observed on the selection and analysis of DNA traces. A 'hierarchy of decisions' as suggested could effectively assist the SoCO to make knowledge and evidence-based decisions for analysing a DNA trace at the crime scene, or forward the trace to the laboratory, and will be valuable in future crime scene practice procedures.

## 6.5 References


1. Antrobus E, Pilotto A. Improving forensic responses to residential burglaries: results of a randomized controlled field trial. *Journal of Experimental Criminology*, 2016;12(3):319-345.
2. Dunsmuir W, Tran C-D, Weatherburn D, Wales N. *Assessing the impact of mandatory DNA testing of prison inmates in NSW on clearance, charge and conviction rates for selected crime categories*, Sydney; NSW Bureau of Crime Statistics and Research: 2008.
3. Roman JK, Reid SE, Chalfin AJ, Knight CR. The DNA field experiment: a randomized trial of the cost-effectiveness of using DNA to solve property crimes. *Journal of Experimental Criminology,* 2009;5(4):345-369.
4. Schroeder DA, White MD. Exploring the use of DNA evidence in homicide investigations: Implications for detective work and case clearance. *Police Quarterly,* 2009;12(3):319-342.
5. Tully LA. *Examination of the use of forensic DNA typing from two perspectives: I. Mitochondrial DNA heteroplasmy. II. The role of DNA typing in criminal investigations*. Doctoral dissertation; University of Maryland: 1998.
6. Wilson DB, McClure D, Weisburd D. Does forensic DNA help to solve crime? The benefit of sophisticated answers to naive questions. *Journal of Contemporary Criminal Justice*, 2010;26(4):458-469.
7. Wilson DB, Weisburd D, McClure D, Wilson DB. Use of DNA testing in police investigative work for increasing offender. *Campbell Systematic Reviews*, 2011;7. Retrieved from: https://www.publicsafety.gc.ca/lbrr/archives/cnmcs-plcng/cn34719-eng.pdf
8. Gangano S, Elliott K, Anoruo K, Gass J, Buscaino J, Jovanovich S, et al. DNA investigative lead development from blood and saliva samples in less than two hours using the RapidHIT™ Human DNA Identification System. *Forensic Science International: Genetics,* 2013;4(1):e43-e44.
9. Salceda S, Barican A, Buscaino J, Goldman B, Klevenberg J, Kuhn M, et al. Validation of a rapid DNA process with the RapidHIT® ID system using GlobalFiler® Express chemistry, a platform optimised for decentralized testing environments. *Forensic Science International: Genetics*. 2017;28:21-34.
10. Mapes A, Kloosterman A, Poot de C, Marion van V. Objective data on DNA success rates can aid the selection process of crime samples for analysis by rapid mobile DNA technologies. *Forensic Science International,* 2016;264:28-33.
11. Chan JB. The technological game: How information technology is transforming police practice. *Criminology and Criminal Justice*, 2001;1(2):139-159.
12. Koper CS, Willis JJ, Woods DJ, Hibdon J. Realising the Potential of Technology in Policing - A Multisite Study of the Social, Organisational, and Behavioural Aspects of Implementing Policing Technologies Report. 2015. Retrieved from: https://www.researchgate.net/profile/James_Willis/publication/278026001_Realising_the_Potential_of_Technology_in_Policing_A_Mutli-Site_Study_of_the_Social_Organisational_and_Behavioral_Aspects_of_Policing_Technologies/links/5579a7b708ae7521587175c8.pdf.
13. Lum C, Koper CS, Willis J. Understanding the Limits of Technology's Impact on Police Effectiveness. *Police Quarterly*, 2017:20(2);135-163.
14. Baber C, Smith P, Butler M, Cross J, Hunter J. Mobile technology for crime scene examination. *International Journal of Human-Computer Studies*, 2009;67(5):464-474.
15. Chan J. Making sense of police reforms. *Theoretical Criminolog,*. 2007;11(3):323-345.
16. Ericson RV, Haggerty KD. *Policing the risk society*, New York: Oxford Press; 1997.
17. Gardner C. The impact of police culture on organisational change: The case of police use of DNA. *New Zealand Sociology*, 2015;30(4):78.
18. Koper CS, Lum C, Willis JJ. Optimising the use of technology in policing: Results and implications from a multi-site study of the social, organisational, and behavioural aspects of implementing police technologies. *Policing: A Journal of Policy and Practice,* 2014;8(2):212-221.
19. Manning PK. Information technologies and the police. *Crime and Justice*, 1992;15:349-398.
20. Manning PK. Information technology in the police context: the "sailor" phone. *Information Systems Research*, 1996;7(1):52-62.
21. Salvemini AV, Piza EL, Carter JG, Grommon EL, Merritt N. Integrating human factors engineering and information processing approaches to facilitate evaluations in criminal justice technology research. *Evaluation Review*, 2015;39(3):308-338.
22. Asten van AC. On the added value of forensic science and grand innovation challenges for the forensic community. *Science & Justice,* 2014;54(2):170-179.
23. Woods D, Dekker S. Anticipating the effects of technological change: a new era of dynamics for human factors. *Theoretical Issues in Ergonomics Science,* 2000;1(3):272-282.

24. HeijdraG. Corporate behavior as driver for implementing new technology. 2013. Retrieved from: https://ideas.repec.org/p/msm/wpaper/2013-13.html.
25. Gruijter M, Poot CJ, Elffers H. The influence of new technologies on the visual attention of CSIs performing a crime scene investigation. *Journal of Forensic Sciences,* 2016;61(1):43-51.
26. Koehler JJ. On conveying the probative value of DNA evidence: Frequencies, likelihood ratios, and error rates. *University of Colorado Law Review,* 1996;67:859.
27. Nickerson RS. Confirmation bias: A ubiquitous phenomenon in many guises. *Review of General Psychology,* 1998;2(2):175.
28. De Gruijter M, Nee C, De Poot CJ. Identification at the crime scene: The sooner, the better? The interpretation of rapid identification information by CSIs at the crime scene. *Science & Justice,* 2017;57(4):296-306.
29. Gruijter M, Poot C, Elffers H. Reconstructing with trace information: Does rapid identification information lead to better crime reconstructions? *Journal of Investigative Psychology and Offender Profiling,* 2017;14(1):88-103.
30. Hazard D. The Relevant Physical Trace in Criminal Investigation. *Journal of Forensic Science and Medicine,* 2016;2(4):208.
31. Inman K, Rudin N. *Principles and practice of criminalistics: The profession of forensic science*. Taylor & Francis Group: CRC Press; 2000.
32. Cook R, Evett IW, Jackson G, Jones P, Lambert J. A hierarchy of propositions: deciding which level to address in casework. *Science & Justice,* 1998;38(4):231-239.
33. Groen W, Berger C. Crime Scene Investigation, archaeology and taphonomy: reconstructing activities at crime scenes. In: Schotsmans E, editor. *Taphonomy of Human Remains: Forensic Analysis of the Dead and the Depositional Environment*. West Sussex: John Wiley & Sons; 2017.
34. Eeden van den CA, Poot de CJ, Koppen van PJ. Forensic expectations: Investigating a crime scene with prior information. *Science & Justice,* 2016;56(6):475-481.
35. Mapes AA. DNA by the Numbers - Locations of useable DNA based on 24,466 crime samples. *Forensic Magazine,* 2015;October/November 2015:8-9.
36. Wyatt D. Practising crime scene investigation: trace and contamination in routine work. *Policing and Society,* 2014;24(4):443-458.
37. IBM Corp. Released 2012. IBM SPSS Statistics for Mav VA, NY: IBM Corp.
38. Mapes AA, Kloosterman AD, Marion van V, Poot de CJ. Knowledge on DNA success rates to optimise the DNA analysis process: from crime scene to laboratory. *Journal of Forensic Sciences,* 2016;61(4):1055-1061.
39. Holyoak KJ, Simon D. Bidirectional reasoning in decision making by constraint satisfaction. *Journal of Experimental Psychology: General,* 1999;128(1):3.
40. Mapes AA, Stoel RD, Poot de CJ, Vergeer P, Huyck M. Decision Support for using mobile Rapid DNA analysis at the crime scene. Under review at *Science and Justice,* August 2017

# Chapter 7

## Mobile DNA Technologies in Crime Scene Investigation: the Legal Framework[1]

*An analysis of the potential use of mobile DNA technologies to analyse DNA traces under the current legislation regarding criminal cases*

**Abstract**

DNA analysis plays an important role in criminal investigation and prosecution today. Legislation regarding DNA technologies has been embedded in the Dutch Code of Criminal Procedure (Wetboek van Strafvordering) for over two decades. However, technological developments in the field of DNA analysis have soared, with the latest advances forecasting a future in which DNA traces can be analysed at the crime scene, using a single device and requiring a simple 'push of the button'. A potential match between the profile of the traces discovered and a suspect's profile in the DNA database could be established within a few hours. It is not clear, however, how these mobile DNA identification technologies may affect the criminal justice procedure. This article therefore surveys the possibilities and impossibilities of using mobile DNA technologies for crime scene investigation in the criminal justice system.

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[1]This chapter is published in Dutch as: Mapes A, Noordam N. Mobiele DNA-technieken bij de forensische opsporing: het juridisch kader. *Expertise en Recht*, 2015;3:88-95.

This study was designed and performed in general by both authors. The legal analysis and interviews were performed by the co-author. The article was written by the first author with contributions from the co-author.

## 7.1 Introduction

Since DNA legislation was enacted on 1 September 1994, DNA analysis has acquired an established role in Dutch criminal procedures (1). DNA analysis is now viewed widely as an effective tool to investigate crimes and serve as evidence for the prosecution. Certainly since the establishment of the DNA database, DNA traces have become an important element in identifying an offender (2-5). The wish to expedite the analysis and interpretation of DNA traces, and to use this technology more frequently, appears to be growing. Nowadays it is feasible to have specific DNA traces analysed by the Netherlands Forensic Institute within just six hours (6).

In recent decades, the analysis of DNA traces has advanced tremendously. DNA profiles suitable for comparative analysis can now be drawn from even highly minimal traces containing just a single cell (7). Thanks to new technological developments in the field of DNA analysis, there are technologies on the market today that can generate a DNA profile from reference (cheek swab) samples within two hours (8-10). It would seem to require just some minor modifications to create a DNA analysis device that is suitable for use at the crime scene itself, where a single push of the button will generate a DNA profile that can perhaps be compared immediately with the DNA database. The picture emerges of future forensic investigation in which it takes just a few hours to obtain a potential match between the profile of a trace obtained at the crime scene and the profile of a person stored in the DNA database, or with the reference profile of for example a suspect.

These developments are proceeding at a very high pace; initial pilot projects to test the use of these technologies in crime scene investigation operated by the Scene of Crime Officers (SoCOs) are already underway in the United States and the United Kingdom (11-14). In the United States, the analysis of DNA traces outside the forensic laboratory appears to concentrate on using the DNA database. There, access to the national DNA database can only be obtained via a forensic laboratory. These laboratories must meet the ‘FBI Quality Assurance Standards’ and the ‘DNA Identification Act’ of 1994 (15, 16). Moreover, comparisons with the DNA databases can only be conducted at specific times. In the United States, it will require an amendment of the law to permit comparing profiles obtained by these technologies to the database. In particular, it is important to safeguard the privacy of the individuals and/or profiles concerned. For the analysis of reference samples and inclusion of the profile in the Combined DNA Index System (CODIS) the progress already led to creating an addendum quality assurance standard by the FBI for DNA databasing laboratories that are performing analysis with mobile DNA technologies (17). Together this shows that, internationally, these technologies are beginning to trickle into the forensic world. No pilots using mobile DNA technologies have yet taken place in the Netherlands, and it is time therefore to outline a legal framework for the use of these systems within the Dutch criminal justice system.

Outside the Netherlands these technologies are also not yet being used for the analysis of crime scene samples. Although this study is based on the Dutch legal framework, it seems that also outside the Netherlands these mobile DNA technologies cannot be used right away on crime scene samples. An important aspect is to get the judicial framework, of integrating the use of mobile DNA technologies by SoCOs, accurate internationally and this study serves as a first step towards that discussion.

The availability of this technology can signal an important change within the criminal justice system. If analyses are performed at the crime scene and comparisons conducted automatically with the DNA database, it will impact the process from the crime scene to the courtroom, and it will likely require legal changes to establish this new working method. The Forensic Science Research Group at the Amsterdam University of Applied Sciences is currently conducting research into the influence of rapid and mobile DNA identification technologies on the work of the SoCO, and into how these technologies can best be used at the crime scene or in a police laboratory.
However, the focus of this article is not on the work of SoCOs or on the optimum use of new technologies, but on the influence of mobile DNA identification technologies on the legal criminal justice procedure. If traces can be analysed more quickly and more easily, this does not necessarily mean that the analysis results can also be legally used for the intelligence process for the identification of perpetrators, and prosecution in criminal cases. As it is, DNA analysis in support of criminal procedure is constrained by various safeguards. The question, therefore, is how the legal system views this development; what are the bottlenecks, and what are the solutions?
These are important questions that must be answered before introducing such technologies in practice. To that end, this study surveys the possibilities and the impossibilities of using mobile DNA technologies in the criminal justice system (18). First we outline the procedure at the police department of forensic investigation, to then indicate how mobile DNA technologies might be incorporated into this process in the future. We then describe the legislation pertaining to DNA analysis, describing the requesting authority to order such research and who needs to perform this research. To further understand this process and the various relevant roles fulfilled by the parties concerned now and in the future, interviews were held with a qualified reporting DNA scientist called the DNA expert, a SoCO, a forensic advisor, a public prosecutor, a lawyer and a judge. The results of this study serve to answer the question whether the current legislation impedes or prohibits the use of mobile DNA technologies by the SoCOs in criminal cases and if so, how these can be eliminated.

## 7.2 Forensic Investigation

A SoCO from the police department of Forensic Investigation is usually the first person at a crime scene, to collect evidence. He or she can collect biological traces, which are then taken to the police forensics department. Under the authority of a public prosecutor, one or more of these traces can then be submitted to a forensics laboratory for further analysis. Inside the laboratory, the trace is treated according to a strict protocol for DNA profiling and for comparing this profile to DNA profiles of traces and individuals stored in the DNA database or with case reference profiles. To conclude the process, the analysis and comparison results are reported by a DNA expert (5). The report, including the findings, is then sent to the public prosecutor and to the police forensics department. The entire process (Figure 1) can take a fair amount of time. A study into the turnaround time of DNA traces, from the crime scene to the DNA report, shows that this process takes 66 days on average for serious crimes, and 44 days on average for high volume crimes (5). These long turnaround times can significantly slow down the intelligence and prosecution process, certainly if the trace results in a DNA database match, which permits the tracking down of a previously unknown suspect. For certain cases and certain traces, expediting this process would be a welcome improvement for the intelligence and prosecution process. By using mobile DNA technologies that enable the generation of a DNA profile from traces at the crime scene, the DNA analysis process could comprise far fewer process steps. Figure 1 shows what the future might look like for the forensic process of DNA analysis of some traces. However, it is not certain whether such a simplification is legally feasible. It is also unclear what the role of the public prosecutor would be, who may wish to use the research results as part of his evidence.

If the DNA profiles, obtained through mobile DNA technologies, are to be used mainly for intelligence purposes the police might make its own decisions on which traces should and which need not be analysed. Should this still require the authority of the public prosecutor or supervisory judge? It also raises the question whether the intelligence phase, to identify offenders, and the presentation of evidence phase should be treated as two separate phases. After all, traces analysed to support the intelligence of identifying a perpetrator can also serve the prosecution in the courtroom.

## 7.3 Mobile DNA Technologies

Various companies and scientists are currently working to accelerate DNA analysis processes and to develop mobile DNA identification technologies (8-10, 19-23). All these technologies have in common that a trace sample can be inserted in a specifically designed ‘cartridge’, without requiring complex sample preparations, and that the entire DNA analysis process can be conducted completely with a single push of the button,

with the objective to produce analysis results within two hours that are qualitatively comparable to the analysis results of renowned laboratories. The idea is that the system can also compare these results directly to internally stored profiles such as reference profiles, or with profiles stored in the DNA database. This implies a highly standardised 'easy-in, easy-out' system, requiring minimum preparation and dispensing with all technological expertise, so that it can be used by for example a SoCO.

We shall not address the current output and quality of these systems here. This study assumes that these systems produce the same results as the standard analysis processes conducted in laboratories. The device will automatically perform any subsequent profile comparisons and present the results with an indication of the reliability margin. The SoCO will not have access to the profiles. Results that fall outside the reliability margin will be blocked, and the system will indicate that a DNA expert is required to perform the profile comparison. The SoCO could then decide to submit the profile result and/or the trace to a forensic laboratory.

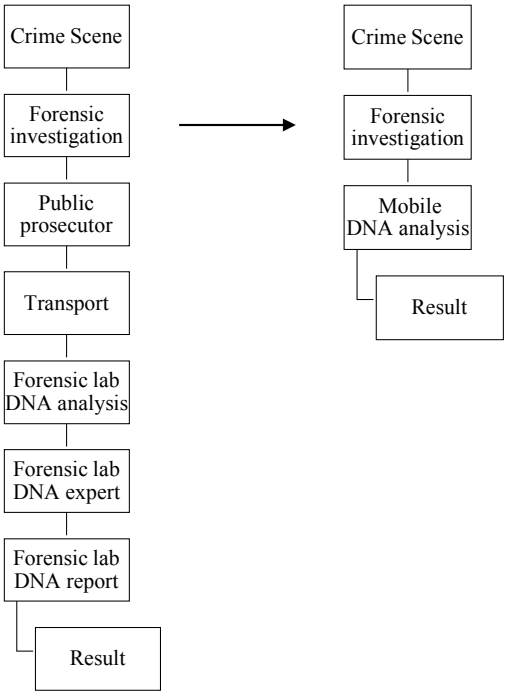



**Figure 1.** Modification of the Forensic Identification Process with Mobile DNA Technologies

## 7.4 The Law

That technological developments are enabling an ever faster means of generating DNA profiles does not mean that these results can simply be used for intelligence and prosecution purposes in criminal cases. DNA analysis as part of criminal procedure is attended by a number of safeguards. These safeguards are detailed in e.g. the Criminal Procedure Code and the DNA (Criminal Cases) Tests Decree. With regard to DNA analysis, Articles 138a, 151a and 195a of the Criminal Procedure Code are particularly pertinent. Article 138a gives a definition of DNA analysis. This definition includes *the analysis of cellular material with the sole purpose of comparing DNA profiles*. The public prosecutor is the authority to order this type of DNA analysis in the interest of a criminal investigation on the basis of Article 151a paragraph 1. The supervising judge has the same authority on the grounds of Article 195a paragraph 1. The second paragraph of both Article 151a and 195a stipulates that the public prosecution officer, respectively the supervising judge, must appoint an expert to perform the DNA analysis who is affiliated with a laboratory that has been designated for the purpose by a general administrative order. For this purpose, Article 7 paragraph 1 of the DNA (Criminal Cases) Tests Decree designates the Netherlands Forensic Institute. Articles 151a paragraph 11 and 195a paragraph 6 of the Criminal Procedure Code stipulate that further regulations regarding the implementation of the articles pertaining to DNA analysis, Articles 151a and 195a, will be issued through or pursuant to general administrative orders. These further regulations regarding the implementation of these articles are contained in the aforementioned DNA (Criminal Cases) Tests Decree. The third paragraph of this decree stipulates how DNA analysis is to be performed. Article 9 paragraph 2 determines that the appointed expert shall perform the DNA analysis according to methods that have been approved upon accrediting the laboratory with which the expert is affiliated. Article 10 paragraph 1 of the Decree stipulates that the expert must draw up a report detailing the results of the performed DNA analysis. This report must fulfil certain criteria, listed in Article 10 paragraph 2, under C and D of the Decree. For example, the report must describe the method used to obtain the DNA profile. The report must also contain the results and the conclusions of the DNA analysis. The question now is whether all the safeguards contained in the detailed DNA legislation are also relevant when deploying mobile DNA technologies and if so, how this will impact the use of a mobile DNA technology in a crime scene investigation.

### 7.4.1 The Legal Possibilities and Impossibilities

As described in the previous paragraph, DNA analysis is defined by Article 138a of the Criminal Procedure Code as the investigation of cellular material with the sole purpose of comparing DNA profiles. If mobile DNA technologies are to be deployed at the crime scene, then this will entail performing a DNA analysis on any cellular material that may

have been found and comparing the DNA profile results, if possible, with the DNA database. The use of a mobile DNA technology thus falls within the definition of DNA analysis as given by the Criminal Procedure Code. This therefore raises the question whether the use of mobile DNA technologies is permissible under current legislation. After all, as the previous paragraph has shown, DNA analysis must comply with a series of safeguards. The use of a mobile DNA technology does not comply with two safeguards prescribed by law with regard to DNA analysis. First, contrary to the provisions of Articles 151a paragraph 2 and 195a paragraph 2 of the Criminal Procedure Code, it is not strictly necessary to appoint an expert to perform the DNA analysis by means of the mobile DNA technology. After all, a SoCO can easily insert traces found at the crime scene in the mobile DNA analysis device. Second, the use of mobile DNA technology does not comply with the requirement stipulated in Article 9 paragraph 2 of the DNA (Criminal Cases) Tests Decree. A mobile DNA technology is not a method of analysis that was approved upon accrediting the laboratory with which the expert is affiliated. We may thus conclude that the use of mobile DNA technologies as described above is not explicitly permitted by the DNA legislation. The use of such technologies can thus not be based on the Criminal Procedure Code articles that specifically address DNA analysis. However, this need not mean that the use of mobile DNA technologies is by definition unlawful, as elaborated below.

According to the legality principle of criminal procedure, such procedure can only be conducted in the manner stipulated by law[1]. This principle holds that every criminal procedural act must be based on the law. This legal basis does not in all cases need to be a specific legal basis. In certain instances, for instance for intelligence purposes, criminal procedural action can be based on the general investigative authority of the SoCO, referred to in Articles 141 and 142 of the Criminal Procedure Code and in Article 3 of the Police Act 2012. The pertinent question here, therefore, is when the general investigative authority offers sufficient legitimacy for intelligence investigative acts for identification purposes, and when such acts require a more specific legal basis. It can be deduced from legislative history that investigative actions for identification purposes that do not violate any fundamental rights can be based on the general investigative authority described in Articles 141 and 142 of the Criminal Procedure Code and in Article 3 of the Police Act 2012.[2] However, this does not mean that investigative acts for intelligence identification purpose that do violate a fundamental right cannot be based on the general investigative authority of SoCOs, by definition. The Dutch Supreme Court has attempted to clarify in a number of rulings when the general investigative authority for intelligence identification purposes provides sufficient legitimacy for criminal procedural actions. According to the Supreme Court, briefly put, Articles 141 and 142 of the Criminal Procedure Code and in Article 3 of the Police Act

[1] Article 1 Criminal Procedure Code. (In Dutch: Artikel 1 van het Wetboek van Strafvordering.)
[2] Parliamentary Papers II 1996/97, 25403, 3, p. 13. (In Dutch: *Kamerstukken II* 1996/97, 25 403, nr. 3, p.13.)

2012 can sufficiently legitimise limited violations of personal privacy.[3] To determine whether any given instance amounts to a limited violation of personal privacy, the Supreme Court will examine the actual circumstances. This includes the duration, the intensity, the place, the goal and the manner of the investigative identification action.[4] If it concerns a manner of identification that violates the privacy, the Supreme Court will also consider whether the method is suited to obtaining a more or less comprehensive picture of the personal life of the individual concerned. If so, then the investigative identification method for intelligence purposes cannot be based on the general investigative authority of SoCOs, and a more specific legal basis is required.[5]
However, the question remains, can mobile DNA technologies be deployed on the basis of the general investigative authority for identification purposes? Using such technologies to analyse traces left at the crime scene represents a limited violation of people's privacy. For example, it does not entail a violation of bodily integrity. No cellular material is taken from the individual concerned. It only entails examining whether traces already present at the crime scene match the profile of a person already contained in the database. Using a mobile DNA technology also does not produce a more or less complete picture of the various aspects of one's personal life. If the result of applying a mobile DNA technology is a match between a detected DNA trace and a profile of a person in the database, then this is just an indication that the individual concerned was possibly present at the crime scene. Using mobile DNA technologies in the intelligence phase can therefore be based on Articles 141 and 142 of the Criminal Procedure Code and on Article 3 of the Police Act 2012.
The subsequent question is: what can the results of using the mobile DNA technology be used for? Can the results be used as evidence in criminal cases? The articles pertaining to DNA analysis in the Criminal Procedure Code do not prohibit using mobile DNA technologies as an identification tool for intelligence purposes. However, the legislative history does suggest that the legislator has wanted to embed DNA analysis within firm safeguards.[6] It seems improbable that the legislator drew up a detailed regulation stipulating the safeguards attending to DNA analysis on the one hand, and on the other would permit DNA analysis that does not comply with this regulation. When

[3] HR 19 December 1995, ECLI:NL:HR:ZD0328, paragraphs 6.4.2-6.4.5. (Zwolsman ruling). The Zwolsman ruling only discusses this authority on the basis of the Police Act (then Article 2 of the Police Act 1993, now Article 3 of the Police Act 2012). Later pronouncements have clarified that this also applies for Articles 141 and 142 of the Criminal Procedure Code. See for example HR 21 March 2000, ECLI:NL:HR:2000:AA5254, paragraph 3.4. (In Dutch: HR 19 december 1995, *ECLI*:NL:HR:ZD0328, r.o. 6.4.2-6.4.5. (Zwolsman-arrest). In het Zwolsman-arrest wordt alleen gesproken over deze bevoegdheid op grond van de Politiewet (toen nog artikel 2 Politiewet 1993, nu artikel 3 van de Politiewet 2012). Uit latere uitspraken blijkt dat dit ook geldt voor de artikelen 141 en 142 van het Wetboek van Strafvordering. Zie bijvoorbeeld HR 21 maart 2000, *ECLI*:NL:HR:2000:AA5254 r.o. 3.4.)
[4] See e.g. HR 21 March 2000, ECLI:NL:HR:2000:AA5254, paragraph 3.5. (In Dutch: Zie hiervoor onder andere HR 21 maart 2000, *ECLI*:NL:HR:2000:AA5254 r.o. 3.5.)
[5] HR 20 January 2009, ECLI:NL:HR:2009:BF5603, paragraphs 3.2 and 3.3 (Thermal imaging camera ruling). (In Dutch: HR 20 januari 2009, *ECLI*:NL:HR:2009:BF5603, r.o. 3.2 en 3.3 (Warmtebeeldkijker-arrest).)
[6] Parliamentary Papers II 1991/92, 22447, 3, p. 5-6. (In Dutch: *Kamerstukken II* 1991/92, 22 447 nr.3, p.5-6.)

drawing up the detailed regulation, the legislator could of course not have foreseen all the developments in the field of DNA analysis. Nevertheless, it may be said that the aspects described by the legislator in the proposed law, which centres mainly on the thorough regulation of the research method, will continue to apply in full. It can therefore be assumed that the results of a DNA analysis will only be admitted as evidence in a criminal case, if the research complies with the demands imposed on such research by the Criminal Procedure Code. Mobile DNA technology does not meet these demands on two counts. As described earlier, this concerns the fact that the use of mobile DNA technology does not necessarily require the involvement of an expert, and the fact that a mobile DNA technology is not a method that has been approved upon accrediting a laboratory. It is for these reasons that the results of a mobile DNA analysis cannot be used as evidence in criminal cases. The conclusion is therefore that mobile DNA technologies lack a basis in the law. As they form a limited violation of people's privacy, mobile DNA technologies can, in our opinion, be based on the general investigative authority set out in Articles 141 and 142 of the Criminal Procedure Code and Article 3 of the Police Act 2012. However, this will not produce results that can be admitted as evidence. The results of a DNA analysis can only be admitted as evidence, if the DNA analysis complied with the demands as imposed by the law.

## 7.5 The Opinion of Professionals from the Criminal Justice System and Safeguards

Aside from the question whether mobile DNA technologies can be used under the current legislation, it is important to examine the safeguards that should surround this type of DNA analysis. To elucidate this matter, a number of interviews were held with professionals within the criminal justice system. Through the authors' own networks and the snowballing method, interviews were held with a forensic expert, a SoCO, a forensic advisor, a public prosecutor, a lawyer and a judge. The interviews do not produce a representative picture of how a certain occupational group views the use of mobile DNA technologies in a criminal investigation. The interviews have however yielded a number of interesting insights with respect to the relevant aspects of using mobile DNA technologies. In combination with the legal analysis, this has resulted in six safeguards that are important to observe when using mobile DNA technologies.

A first safeguard to observe is that the public prosecutor must be the requesting authority to decide on using the technology. Under current law, the public prosecutor is the authority that decides in most cases, and certainly during the intelligence investigation, on the use of DNA analysis on the basis of (amongst other sources) Article 151a

paragraph 1 of the Criminal Procedure Code.[7] It is desirable to keep it this way when using mobile DNA technologies. The interviewed public prosecutor formulated this as follows:

*"I imagine that when I arrive at the crime scene and a SoCO explains to me what they found and where, and why this is potentially a perpetrator trace, that I will still have some say in the matter as well."*

The public prosecutor will have to decide in each individual case whether the use of mobile DNA technology is lawful. This does not mean that the public prosecutor must always visit the crime scene concerned; consultation by telephone is also possible. The public prosecutor will need to account for his decisions on this point, should the case come to trial.[8]

A second important safeguard when using mobile DNA technologies is that a regulation must be in place containing prescriptions regarding the device used. This regulation could for instance contain technical specifications, the definition of a maximum error margin, and instructions on how to clean the device. Such a regulation would be comparable to a Breath Analysis Regulation or the DNA Sampling in Criminal Cases Regulation. When asked whether it would be useful to implement such a regulation, the interviewed SoCO replied:

*"Yes, absolutely. But this will also prove tricky. Many of the people who are deliberating the issue have no understanding of a crime scene investigation, but only think from a policy angle. They don't look at the optimum way of putting something into practice."*

This ties into a third relevant safeguard, namely to implement a protocol regulating the use of different types of traces for mobile DNA analysis by the SoCO. After all, one type of trace will offer a better chance of successfully obtaining a DNA profile than another trace. It will depend on the minimum amount of DNA that the device requires to generate a profile to determine which types of traces can and which cannot be analysed by mobile technology, and which types of traces may need to be submitted to a forensic laboratory. It is therefore essential to develop an evidence-based decision-making protocol for the mobile analysis of DNA traces.

A fourth important safeguard is that SoCOs should receive additional training in how to use the device in practice. The interviewed judge, when asked whether he believed that a SoCO should be permitted to use the device, replied:

[7] In some cases, this can be the supervising judge, on the basis of Article 195a paragraph 1 of the Criminal Procedure Code. (In Dutch: In sommige gevallen kan dit ook de rechter-commissaris zijn op basis van artikel 195a, eerste lid, van het Wetboek van Strafvordering.)

[8] See Article 148 of the Criminal Procedure Code. (In Dutch: Zie hiervoor artikel 148 van het Wetboek van Strafvordering.)

*"I think that it should be a SoCO. Or at least someone who is thoroughly aware of all the things that can go wrong."*

Additional training can make the SoCO (more) aware of the potential risks.
In this regard, the interviewed public prosecutor remarked:

*"I think that it's important that the person who inserts the material in the device does so in a proper and reliable manner."*

On the subject of this safeguard, the interviewed forensic advisor made another suggestion:

*"There are plenty of SoCOs who also have ancillary tasks. For example, one will concentrate on fire investigations and another examines cars, and so you could have a number of SoCOs who have DNA as their special domain."*

Providing SoCOs with additional training does not mean that they need to follow the full education programme to become a DNA expert, however. The additional training would serve to ensure that they are better equipped to deal with the device and with the results it produces.
A further relevant safeguard is to be able to have recourse to contra-expertise. The interviewed criminal lawyer saw this as an important safeguard:

*"That should also really be part of those safeguards. That it can only be done if you know for sure that you'll have enough material left to also run a second, more extensive test."*

The suspect should not be worse off when mobile DNA technology is used in the investigation. With regard to regular DNA analysis, the suspect – if he is the only known suspect and there is not enough cellular material for a contra-test – is entitled to designate the expert who will perform the DNA analysis.[9] The suspect may not be deprived of this right, only because a mobile DNA technology was used.
Finally, it is important that the situation at the crime scene and the subsequent process are recorded meticulously. It should be possible for all people involved to reconstruct exactly what happened at the crime scene. The reason is that the defence lawyer will

[9] According to Articles 151a paragraph 4 and 195a paragraph 3 of the Criminal Procedure Code. The expert that identifies the suspect must be affiliated with one of the designated laboratories. (In Dutch: Aldus artikel 151a, vierde lid, en artikel 195a, derde lid, van het Wetboek van Strafvordering. Wel moet de deskundige die de verdachte aanwijst verbonden zijn aan één van de aangewezen laboratoria.)

generally not be involved in the case yet, at the time that the crime scene is investigated. The interviewed criminal lawyer commented on this as follows:

*"I insist that, as a lawyer, you need to know what happens at the crime scene with regard to securing forensic traces, and all the decisions that may be made in the process by the SoCOs or experts of the Netherlands Forensic Institute, for instance to secure a trace."*

## 7.6 Conclusions and Discussion

Under the current legislation, the conclusion regarding the use of mobile DNA technologies by a SoCO is two-fold. On the one hand we can conclude that mobile DNA technologies can be used for identification intelligence purposes without a specific basis in the law. On the other hand, the result of a mobile DNA technology cannot be used as evidence in criminal cases. For the latter purpose, the trace must be handled by a DNA expert and analysed at a designated, accredited laboratory. This impediment could be dispensed by adapting mobile DNA technologies to the current legislation, for example by involving a DNA expert in the DNA analysis at the crime site who is affiliated with a laboratory designated by a general administrative order, and to accredit the mobile DNA technology and its usage procedure. Another option would be to amend the law.
If it were decided to not amend the law with a view to using mobile DNA technologies, and to only use the technology for intelligence purposes, then this would imply duplicate research work if the analysis results are to be used as part of the evidence. After all, in order to use the analysis result as evidence, the trace must be analysed by a forensic laboratory. It should however be noted that the intelligence phase, to identify a perpetrator, and the evidence phase are inextricably linked, to the effect that if a DNA trace turns out to be important for intelligence and results in the identification of a suspect, then this same DNA trace can be equally important for the evidence phase.
Thus, what matters is not so much the specific actions performed in a certain phase; regarding the intelligence phase, what mainly matters is the extent to which the DNA analysis violates a person's fundamental rights, and regarding the evidence phase, what matters is the thorough regulation of the analysis method. One could argue that the two aspects are important to both the identification and the evidence phase, so that this distinction is actually a bit odd. Therefore, the somewhat more flexible rules that apply for the intelligence phase do not seem practicable for the use of mobile DNA technology, when the result is also required for the evidence phase. In practice, it might therefore be advisable for the criminal justice system to drop this distinction between the two phases, particularly where DNA traces are concerned. Analysing DNA traces is not only important to tracking down a suspect, but also to including or excluding other suspects or people connected to the crime. Both to track down a suspect and to reconstruct the crime, the rapid analysis of a DNA trace may be essential.

Our legal analysis shows that the use of mobile devices for DNA analysis by the police must be attended by the following safeguards: 1) the public prosecutor is the requesting authority, 2) the implementation of a regulation detailing the prescriptions that the device must comply with, 3) implementation of a protocol to regulate the type of DNA traces to be used, 4) SoCOs receive additional training, 5) contra-expertise must remain possible, and 6) the situation at the crime scene and the subsequent process must be recorded meticulously. Naturally, the quality of the technology will always determine which traces can be followed in this process, and it should always remain possible to apply contra-expertise to the secured trace. Another important question pertains to the role of the DNA expert in using these technologies. At present, the DNA expert designates the analyst who will perform a DNA analysis in the laboratory. When using a mobile DNA analysis device, the role of the analyst is actually fulfilled by the device, as the analysis is performed automatically by the device at just a push of the button. The device can also perform part of the profile comparisons, so that, in the future, the DNA expert will not necessarily need to be involved in all profile comparisons.
The device could be calibrated in such a way that it only reports the results of very clear and straightforward comparisons of single profiles, and that it indicates that the obtained profile is not suitable for comparison purposes if the analysis yields an incomplete DNA profile, or a mixed profile without a clear main profile. In that case the results could be submitted to a DNA expert.
In this way, the introduction of mobile DNA technologies could result in assigning 'simple' DNA analysis tasks to the police. The SoCO who operates the device will need to learn the relevant new skills, and it might no longer be necessary to involve a DNA expert in this type of DNA analysis. Using the mobile DNA analysis device, and the concomitant interpretation and reporting of results, could become a new specialism within the police forensic department. If the analysis of 'simple' traces can be assigned to the police, then it would free up time and capacity at the forensic laboratories for the complex, more challenging DNA analyses and profile comparisons. Another option is to have DNA experts and laboratory scientists work decentrally at police forensic departments, under the auspices of an accredited forensic laboratory. In that case the SoCO of the police could work directly alongside the laboratory scientist and/or expert who can rapidly perform the analysis on the spot and in accordance with the legal standards. This would likely do away with many of the legal constraints.

It is clearly necessary to create a clear regulation for the use of mobile DNA technologies, attending both to the manner in which the research should be conducted and to how the evidence and the acquired results can be stored safely. The use of such technologies in practice furthermore depends on the ability to formulate an evidence-based decision-making model with guidelines for subjecting DNA traces to analysis by

a mobile DNA analysis device or by a forensic laboratory. Such a model is under development in a study that is currently underway.

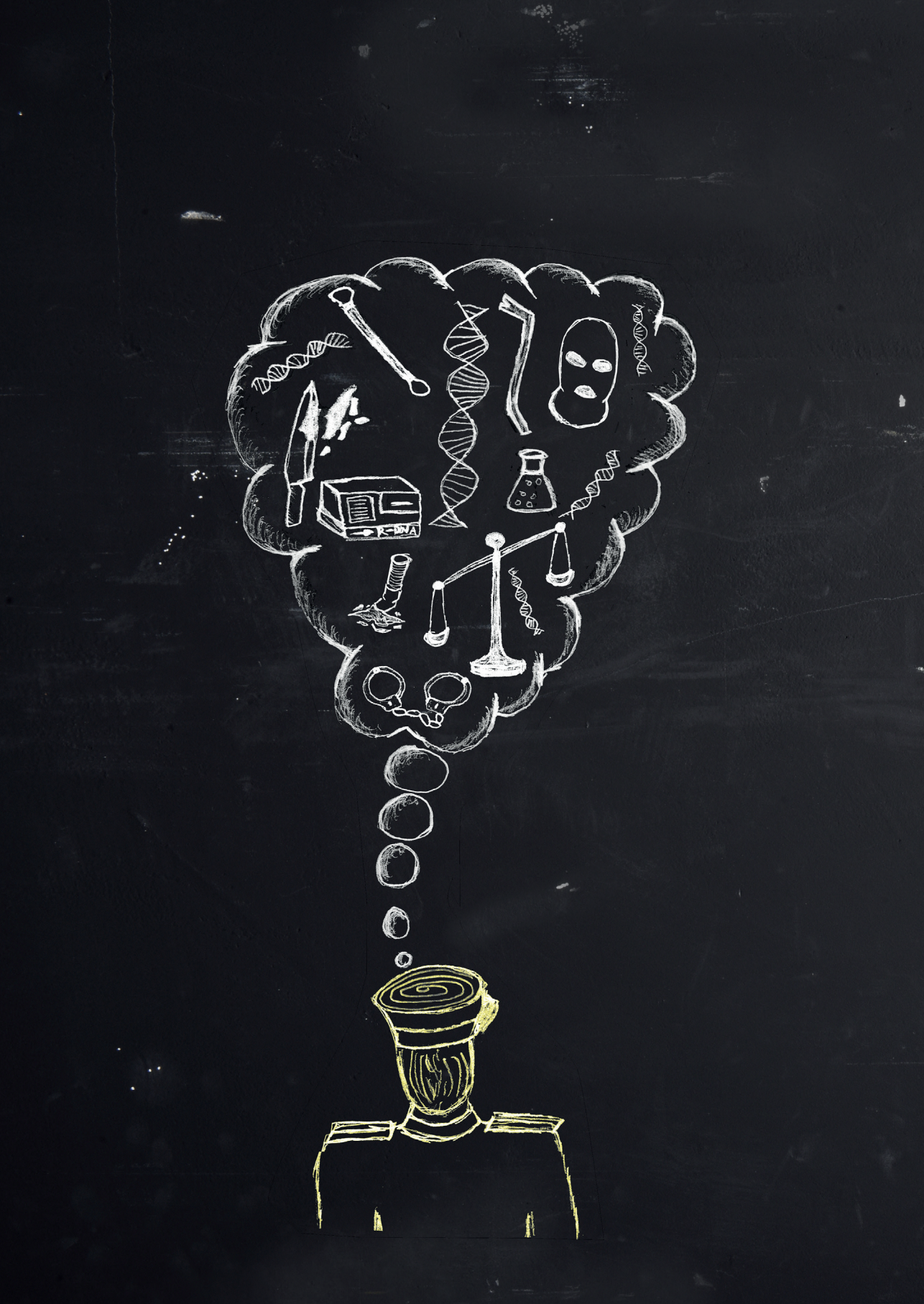
It seems inevitable that mobile DNA technologies will eventually come into use and that they will permanently change the field of forensic investigation. How these technologies will be introduced, and how they will fit into the process of identification for intelligence and prosecution, is still an open question for politicians to consider. Irrespective of the decisions that will be taken, however, it is advisable to create a specific legal basis and to formulate practical guidelines for the use of mobile DNA technologies in the process of identification for intelligence and prosecution.[10]

## 7.7 References


1. Buiter L, Dubelaar M, Haesen N, Malewicz R, Nijboer J, Roos TAd, et al. *DNA-onderzoek in opsporing en bewijsvoering in strafzaken*. Leiden;Universiteit Leiden, Seminarium voor Bewijsrecht; 2003.
2. Bieber FR. Turning base hits into earned runs: Improving the effectiveness of forensic DNA data bank programs. *Journal of Law Medicine, and Ethics,* 2006;34(2):222-233.
3. De Knijff P. Bewijsvoering op basis van DNA-profielen en-databases. *Justitiële Verkenningen Forensische Expertise,* 2004;30(1):39-49.
4. Fraser J, Williams R. *Handbook of forensic science*. New York, NY: Routledge; 2009.
5. Mapes AA, Poot de CJ, Kloosterman AD. De rol van DNA bij het vinden van een dader: het succesverhaal rond DNA als opsporingsmiddel in perspectief. *Tijdschrift voor Criminologie,* 2014;56(3):29-46.
6. Nederlands Forensisch Instituut. DNA-6 uur. Retrieved from: https://mijnnfi.nl/pdc/biologisch/dna-haar-vingersporen-bloed/dna-6-uur.html2014
7. Kloosterman AD, Meulenbroek AJ. DNA-onderzoek van minimale biologische sporen; gevoelige problematiek. *Analyse,* 2009;64(8):232-241.
8. Gangano S, Elliott K, Anoruo K, Gass J, Buscaino J, Jovanovich S, et al. DNA investigative lead development from blood and saliva samples in less than two hours using the RapidHIT™ Human DNA Identification System. *Forensic Science International: Genetics,* 2013;4(1):e43-e44.
9. LGC-Forensics. DNA for forensics – ParaDNA. 2013. Retrieved from: http://www.lgcgroup.com/productsservices/forensics/dna-for-forensics/paradna/.
10. Mukhopadhyayis R. DNA microfluidics – Forensic flow. *Chemistry World,* 2011:50-3.
11. Dawnay N, Stafford-Allen B, Moore D, Blackman S, Rendell P, Hanson EK, et al. Developmental Validation of the ParaDNA® Screening System-A presumptive test for the detection of DNA on forensic evidence items. *Forensic Science International: Genetics,* 2014;11:73-79.
12. O'Callaghan J. DNA-testing for crime scene investigations will soon identify criminals in a matter of hours. 28 July 2014. Retrieved from: http://www.dailymail.co.uk/sciencetech/article-2708277/DNA-testing-crime-scene-investigations-soon-identify-criminals-matter-HOURS.html
13. O'Neill S. New DNA tests will identify killers in hours. 28 July 2014. Retrieved from: http://www.thetimes.co.uk/tto/news/uk/crime/article4159345.ece?shareT.
14. White M. Police trial on-the-spot DNA testing machines. 9 August 2014. Retrieved from: http://news.sky.com/story/1316007/police-trial-on-the-spot-dna-testing-machines.
15. Maryland v. King. Supreme Court of the United States; 2013.
16. Tan E, Turingan RS, Hogan C, Vasantgadkar S, Palombo L, Schumm JW, et al. Fully integrated, fully automated generation of short tandem repeat profiles. *Investigative Genetics*, 2013;4:16.
17. FBI. Addendum to the quality assurance standards audit for DNA databasing laboratories performing rapid DNA analysis and modified rapid DNA analysis using a rapid DNA instrument. 2014. Retrieved from: https://www.fbi.gov/about-us/lab/biometric-analysis/codis/audit-document-for-rapid-dna-qas-addendum-effective-12-1-2014.
18. Noordam L. Snelle DNA-identificatie: de juridische (on)mogelijkheden. 2014. Retrieved from: http://njb.nl/Uploads/2014/1/MASTERSCRIPTIE-SNELLE-DNA-IDENTIFICATIE.pdf.


[10] On 6 June 2014, the project group 'Local DNA' was established to accomplish this. This is a co-creation project by the Police, the Public Prosecution Service, the Netherlands Forensic Institute and the Forensic Science Research Group of the Amsterdam University of Applied Sciences. The goal is to formulate, in consultation with the various system partners, legal and practical guidelines to ensure the safe use of mobile DNA technologies.

19. Bruijns B, Kloosterman A, de Bruin K, van Asten A, Gardeniers J, editors. Presumptive Human Biological Trace Test for Crime Scenes, based on Lab-on-aChip Technology - "HuBiTT. 6th European Academy of Forensic Science Conference; 2012; the Hague, the Netherlands.
20. LaRue BL, Moore A, King JL, Marshall PL, Budowle B. An evaluation of the RapidHIT system for reliably genotyping reference samples. *Forensic Science International: Genetics,* 2014;13:104-111.
21. GE Healthcare Life Sciences. DNAscan Rapid DNA Analysis System data file for forensics. 2013. Retrieved from:. http://www.gelifesciences.com/webapp/wcs/stores/servlet/productById/nl/GELifeSciences/29022852.
22. Lockheed Martin. Lockheed Martin IntrepID S2A-90 Brochure. 2013. Retrieved from: http://www.lockheedmartin.com/content/dam/lockheed/data/isgs/documents/ISGS-IntrepIDBrochure-1-24-12.pdf.
23. NEC. NEC Tests its Portable DNA Analyzer with Japan's National Research Institute of Police Science. 22 November 2012 Retrieved from: http://www.nec.com/en/press/201211/global_20121122_02.html.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# Chapter 8

## Decision Support for using Mobile Rapid DNA Analysis at the Crime Scene[1]

**Abstract**

Mobile Rapid DNA technology is close to being incorporated in to crime scene investigations, with the potential to identify a perpetrator within hours. However, the use of these techniques entails the risk of losing the sample and potential evidence, because the device not only consumes the inserted sample, but also is less sensitive than traditional technologies used in forensic laboratories. Scene of Crime Officers (SoCOs) therefore will face a 'time/success rate trade-off' issue when making a decision to apply this technology.

In this study we designed and experimentally tested a Decision Support System (DSS) for the use of Rapid DNA technologies based on Rational Decision Theory (RDT). In a vignette study, where SoCOs had to decide on the use of a Rapid DNA analysis device, participating SoCOs were assigned to either the control group (making decisions under standard conditions), the Success Rate (SR) group (making decisions with additional information on DNA success rates of traces), or the DSS group (making decisions supported by introduction to RDT, including information on DNA success rates of traces).

This study provides positive evidence that a systematic approach for decision-making on using Rapid DNA analysis assists SoCOs in the decision to use the rapid device. The results demonstrated that participants using a DSS made different and more transparent decisions on the use of Rapid DNA analysis when different case characteristics were explicitly considered. In the DSS group the decision as to whether to apply Rapid DNA analysis was influenced by the factors 'time pressure' and 'trace characteristics' like DNA success rates. In the SR group, the decisions depended solely on the trace characteristics and in the control group the decisions did not show any systematic differences on crime type or trace characteristic.

Guiding complex decisions on the use of Rapid DNA analyses with a DSS could be an important step towards the use of these devices at the crime scene.

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[1]This chapter is submitted to *Science & Justice* as: Mapes AA, Stoel RD, Poot de CJ, Vergeer P, Huyck M. Decision Support for using mobile Rapid DNA analysis at the crime scene.

This study was designed, performed, analysed and published as an article by the first author, the co-authors advised on the set-up of the study and made suggestions and recommendations for the article. RD Stoel and P Vergeer provided expertise on Rational Decision Theory and designing the formula. M Huyck provided expertise on forensic investigation at the NYPD for setting up the study.

*"The goal of decision theory is to help choose among actions whose consequences cannot be completely anticipated, typically because they depend on some future or unknown state of the world. Expected utility theory handles this choice by assigning a quantitative utility to each consequence, a probability to each state of the world, and then selecting an action that maximizes the expected value of the resulting utility. This simple and powerful idea has proven to be a widely applicable description of rational behaviour." (Parmigiani (1), 2009, p. 56).*

## 8.1 Introduction

Mobile and Rapid DNA analysis techniques are currently finding their way to the forensic crime scene (2, 3). Analysing DNA evidence with this mobile technology may result in valuable intelligence information for the Criminal Justice System (CJS), with the power to identify a suspect within two hours. However, the use of these techniques entails the risk of losing the sample and potential evidence, because the Rapid DNA analysis technology not only consumes the inserted sample, but is also less sensitive than traditional technologies used at the forensic laboratory (4). The decision to use Rapid DNA analysis at the crime scene will always be made with uncertainty as the results of the analysis are unknown. Rapid DNA analysis and laboratory analysis differ from each other on the variables 'time' and 'sensitivity'. The decision maker can choose between receiving fast DNA analysis results with a less sensitive Rapid DNA device, which involves the risk of losing evidence that might have been preserved in the laboratory, or receiving feedback much later through more sensitive laboratory analysis, which involves the risk of losing time to identify and apprehend the offender. Thus, there is a trade-off between *'time'* and *'success rate',* and decision makers have to choose between fast but less certain results and slow but more certain results.
Scene of Crime Officers (SoCOs) are accustomed to making decisions on analysing traces with uncertainty; because SoCOs infer both the relevance of the trace, and the possible utility of the trace analysis from the information they receive at the crime scene. What really happened during the commission of the crime is unknown, and ideally will be discovered during the investigation. Most of the SoCOs' decisions are likely based on best practices (5) and intuition (6-8). Because intuition involves unconscious processes, it remains unclear which factors underlie these intuitive decisions. Intuition can therefore lead to biased decision-making (7, 9). A previous study on the use of Rapid DNA devices showed that SoCOs perform more analysis when a Rapid DNA device is available, including analysis of traces with a low success rate (10). This reliance on technology may initially be due to a form of availability bias - because the device is available it is used. The technological reliance may additionally be due to a technological 'escalation of commitment'; once the technology provides a positive result, a rational decision maker may be more likely to gain confidence in this

technology, and tends to commit to using the technology (11), even though this might not always be the best decision. Another important factor could be the influence of emotion on the decision-making process, potentially causing a form of mood bias. For instance, when a case has a high social impact, a personal desire to rapidly identify a perpetrator could negatively affect a rational decision. It therefore seems useful to guide decisions on DNA analyses of traces with explicit consideration of relevant factors. A proposed 'hierarchical decision model' can potentially guide SoCOs in their decision-making in selecting traces for DNA analysis, by considering the type of crime, the probative value of the evidence, and the DNA success rate of the trace (4, 10). However, this model is considered incomplete for Rapid DNA analysis, as it does not take into account the time/success rate trade-off. It is important to understand whether the factors 'time' and 'sensitivity' influence decision-making on using Rapid DNA analysis and how we could further assist the SoCO in this decision-making process.

Deciding on the use of Rapid DNA analysis in a particular case is a binary decision problem: either to use or not to use Rapid DNA analysis resulting in either a DNA profile or no DNA profile. Therefore, four possible outcomes need to be considered before deciding to use Rapid DNA analysis. Each of these outcomes has specific consequences. Especially critical in this complex choice are the consequences of a 'wrong' decision, leading to the negative situation of not obtaining a DNA profile (e.g. no perpetrator identification). This can either be a *true negative slow result* through laboratory analysis that comes after weeks or months, or a *true or false negative rapid result* through using Rapid DNA, in this case it is unknown whether the negative result would have led to a profile in the laboratory or not.

In order to reduce the complexity of decision-making and to minimise potential human errors in processing information associated with best-practices and intuition, such as concentrating on the most salient outcome or on ones' own past experiences, without considering all the different alternatives and probabilities - a coherent and rational way of making decisions about using Rapid DNA analysis that can endure courtroom scrutiny is a necessity. For this purpose, we design and test a Decision Support System (DSS) to support decisions on the use of a Rapid DNA device to analyse traces based on Rational Decision Theory. Rational Decision Theory (RDT) could serve as a method to systematically evaluate all opportunities and risks before making a decision (1). For that reason, our study focuses first on designing this DSS and second on testing the effect of the DSS in an experimental setting, through the use of a vignette study. This way we can test whether the quality of the decision-making on the use of a mobile Rapid DNA device can be enhanced by the developed DSS.

The central research question in this paper is: *Does a Decision Support System that guides SoCOs to explicitly think about the impact of their decisions positively influence decisions on the use of mobile Rapid DNA technologies?*

In the experimental set-up, participating SoCOs were assigned to the *control group* (making decisions under standard conditions), the *Success Rate group (SR)* (making decisions with additional information on (Rapid-) DNA success rates of traces), or the *Decision Support System group* (DSS) (making decisions supported by a Decision Support System, including information on (Rapid-) DNA success rates of traces).
The use of RDT to guide decisions has been studied in different forensic and legal contexts for years (1, 12-15). For forensic identification purposes, this theory is often used and tested in a model as a way for scientists to structure arguments to reduce uncertainties and avoid fallacious interpretations (12, 16-18). A model might also support decision-making processes at the crime scene by giving coherent means of combining elements to reach a decision when the consequences of a choice are uncertain (18, 19). Within legal matters, RDT is also slowly finding its way into practice where quantifying decisions to convict or acquit a defendant beyond reasonable doubt could support judicial decision makers (7, 13, 20, 21). These studies show that the decision problem that goes with conducting Rapid DNA analyses in criminal investigations could benefit from this approach. The basic idea behind rational decision-making with RDT is that a complex decision problem can be solved more effectively by deconstructing it into separate segments. Instead of dealing with the problem as a whole, the decision-maker analyses the components and creates models of the problem's components. These segments are then merged to generate an overall model of the decision situation (22).
Through the use of this RDT concept, a simplified DSS was designed to support SoCOs in their decision to perform or not to perform Rapid DNA analysis at a crime scene. In this complex decision two elements are of importance: 1) the nature of the trace (the associated DNA success rate) and 2) the nature of the case (the associated significance and time sensitivity of the crime). It is expected that this DSS can support the SoCOs in their decision process, as they would be compelled to explicitly evaluate opportunities and risks, taking them into account before deciding to use Rapid DNA analysis. For this purpose, the next paragraph focuses on explaining the specifically designed DSS where first, the RDT is explained in terms of DNA success rates; and second, RDT is used to demonstrate how the factors of the case in terms of associated significance and time sensitivity of the crime will result in a numerical threshold value to rationalise the Rapid DNA analysis decision. The subsequent paragraphs show the experimental set up we designed to test the effect of the DSS, and the results of this test. Finally, both the designed DSS as well as the effect of the DSS are discussed in terms of improving decision-making at the crime scene when Rapid DNA analysis becomes available.

## 8.2 A DSS for Rapid DNA

Rational Decisions Theory suggests that at least two elements are needed to make a decision. For the Rapid DNA analysis dilemma this would be: 1) the success rate for

Rapid DNA analysis and 2) a threshold level for this success rate for when to decide for Rapid DNA analysis. Therefore, when the Rapid DNA success rate of a certain trace is higher than the set threshold level for Rapid DNA analysis, the rational decision would be to rapidly analyse the sample; when the Rapid DNA success rate is lower, the rational decision would be *not* to analyse the sample with Rapid DNA. This concept is explained in more detail in the following subsections.

### 8.2.1 Element 1) Probability of a Rapid DNA Profile

The first element in the Rapid DNA analysis decision process relates to the type of trace, and the Rapid DNA success rate of the trace. Rapid DNA analysis is less sensitive than laboratory analysis; therefore, the decision to use a Rapid DNA device depends on the laboratory success rate and the sensitivity of the Rapid DNA device (4, 23). From previous studies we know for example that a sample from a ski mask (also typed as a balaclava) has a laboratory success rate of 90% and an expected Rapid DNA success rate of 85% (4). This means that 10% of the time a DNA profile will not be obtained using Rapid DNA analysis which is the 'correct' negative result (meaning that laboratory analysis would not have produced a DNA profile) and 5% of the time a false negative result is obtained (meaning that a DNA profile would have been generated in the laboratory, but not with Rapid DNA analysis) due to the lower sensitivity of the Rapid DNA analysis device.

Previous research offered the opportunity to determine these success rates for many traces (4, 23). Therefore, Element 1 in this designed DSS can be considered a given, and can be used for making rational decisions on Rapid DNA analysis for several types of traces.

### 8.2.2 Element 2) Rapid DNA Analysis Threshold Level

In order to compare the probability of obtaining a Rapid DNA profile with the threshold for Rapid DNA analysis we need to quantify this threshold. The threshold can differ between individuals and across crime types. Although it is desirable to find universal thresholds for specific case variables, the values given to the thresholds are, by definition, personal and therefore always the choice of the decision-maker (19). Therefore, we use several general rules in our model. Variables that are relevant in this respect would be: the perpetrator-relatedness of a trace, the laboratory DNA success rate of the trace, the quantity of other relevant traces found at the crime scene, and the type of crime being investigated. All variables that are considered can be incorporated in the model in principle.

We developed a simple model with only three variables: the type of crime investigated, the time pressure, and the type of trace to be analysed. Other variables that might influence this choice, such as the quantity of available traces, the perpetrator-relatedness

of the traces, and laboratory DNA success rates of the traces, remain constant in our model.
The most important feature of the mobile Rapid DNA analysis device is the speed at which it can generate profiles; therefore, we included time pressure as a factor in our model, which is related to the factor crime type. Due to time pressure, we generally expect (not considering the crime type) an urgency to generate a rapid DNA profile, and therefore we expect SoCOs to give more weight to the rapidity than to the sensitivity of the method, resulting in lower thresholds in a serial case than in a singular case. In singular cases, we expect SoCOs to give more weight to the sensitivity of the method used than to the speed. In relation to the crime type, we expect this effect to be related to the seriousness of the case. For example, rapidly obtaining a DNA profile in a serial homicide case is of higher social value than rapidly obtaining a DNA profile in a serial burglary case.

*From values to numbers*
When the decision to analyse a DNA trace has been made, a rational decision maker acknowledges and considers the variables and their values, and proceeds by assigning numerical 'weights' which are all related to one another, and to the four possible outcomes that can occur (1).
The two positive outcomes that can occur are:

γ) *Using* Rapid DNA analysis and obtaining a DNA profile
β) *Not using* Rapid DNA analysis (but laboratory analysis instead) and obtaining a DNA profile

Whereas the two negative outcomes are:

δ) *Not using* Rapid DNA analysis (but laboratory analysis instead) and *not* obtaining a DNA profile
α) *Using* Rapid DNA analysis and *not* obtaining a DNA profile' (Figure 1).

Decision makers want to avoid not obtaining a DNA profile and losing precious time. The decision maker has two options: analyse the trace by Rapid DNA or by regular DNA. Unfortunately, there is always a probability that a decision maker ends up in a situation of not obtaining a DNA profile α (a fast true or possibly a false negative) or δ (a slow true negative). When choosing the option: 'Rapid DNA', the decision-maker could end up in situation α. When choosing the option: 'laboratory DNA', the decision maker could end up in situation δ. Assigning weights to each of the four situations (α, β, γ, and δ) would result in a decision threshold for when to opt for Rapid DNA analysis. Based on previous in-house research with Dutch SoCOs conducted to define potential

suitable values for the designed cases in the experiment, four appropriate threshold options were chosen (Figure 1). These cases will be further explained in paragraph 3, section *The crime scenes.*

As an example, Option 1 in Figure 1 shows the two situations with positive consequences: '*obtaining a DNA profile rapidly (γ)'* is rated '100', and *'obtaining the profile at the laboratory (β)'* is rated '10'. This means that obtaining DNA profiles rapidly is considered 10 times more desirable than obtaining DNA profiles from the laboratory at a later date (γ is 10 times higher than β). The two situations with the negative consequence resulting in *no* DNA profile are rated as '50' for *rapid analysis (α)* and as '5' for *laboratory analysis (δ)*. This shows that, in this example, more emphasis is placed on obtaining positive results rapidly than on avoiding negative consequences. In this case, the most positive consequence (obtaining a DNA profile rapidly, γ) is rated 2 times higher than avoiding the most negative consequence (potential false negative when not obtaining a profile rapidly, α) (α is 2 times higher than γ).

In another option, such as Option 4 in Figure 1, the weights of these four outcomes are different. In this option, more emphasis is placed on avoiding the most negative consequence *(α),* which is rated as '500'. In addition, the most positive consequence (γ) is valued less in this option, this situation is now rated '50'. In this option, avoiding the most negative consequence is considered 10 times more important to avoid than obtaining a DNA profile rapidly in the most positive situation (α is 10 times higher than γ).

By assigning weights to the four possible situations that can occur, the importance of the outcomes can differ and be quantified. The outcome of the Rapid DNA analysis threshold further depends on the laboratory DNA success rate of the traces, because this defines the maximum success rate of the Rapid DNA analysis. Considering these aspects, the numerical threshold value to opt for Rapid DNA analysis can be computed. Based on RDT, taking into account the weight of the four consequences and the probability of a negative laboratory result, it can be mathematically calculated that deciding to use Rapid DNA analysis is preferable when the probability of obtaining a Rapid DNA profile of a certain trace is higher than the calculated threshold (see the Box *Derivation the formula used for setting thresholds,* for the formula used to calculate the thresholds).

In Option 1, this would mean that when the Rapid DNA success rate of a certain trace is higher than the calculated threshold of 39% it is rational to decide to use Rapid DNA analysis. For Option 4, this would mean that the Rapid DNA success rate of this trace needs to be higher than the calculated threshold of 93% to decide for Rapid DNA analysis.

*Making the decisions*

The final step in the development of this Decision Support System is to combine the calculated threshold value (Element 2) with the probability of obtaining a Rapid DNA profile from a certain trace (Element 1). When this Rapid DNA success rate crosses the threshold, the decision maker should decide to use the Rapid DNA device, if not, the rational decision would be to not use the Rapid DNA device.

For instance, when a ski mask is collected as evidence, the *Rapid DNA* success rate of 85% exceeds the set threshold value of 39% from Option 1 in Figure 1, and the decision should therefore be made to use Rapid DNA analysis.

**There are four possible situations that can occur when deciding on the use of Rapid DNA analysis as described in situations γ, β, δ and α. You can:**

| | **Profile is obtained*** | | **No profile is obtained** | | |
|---|---|---|---|---|---|
| | γ) Analyse the DNA-sample with Rapid DNA and a profile is obtained. You get this most positive result within 2 hours. | β) Analyse the DNA-sample at the laboratory and a profile is obtained. You get this positive result within 45 days | δ) Analyse the DNA-sample at the laboratory and no profile is obtained. You get this negative result in 45 days. | α) Analyse the DNA-sample with Rapid DNA and no profile is obtained. You get this most negative result within 2 hours. *This could be because there is actually no profile or because Rapid DNA is less sensitive and therefore did not measure the profile. Whereas a profile might have been obtained in the lab. Therefore possibly losing evidence.* | **Results in threshold |
| **Option 1** | 100 | 10 | 5 | 50 | 39% |
| **Option 2** | 50 | 10 | 5 | 100 | 72% |
| **Option 3** | 100 | 10 | 5 | 100 | 54% |
| **Option 4** | 50 | 10 | 5 | 500 | 93% |

**Obtaining a profile could lead to identification of a perpetrator*

*** During the experimental study the thresholds were provided after choosing one of the four options*

Explanation

The numbers listed in each option are all related to one another. This means for instance, that obtaining a profile at the laboratory (β) in each option (1-4) has an absolute number of 10. However, the actual strength of the number is relative, as it needs to be compared to the other numbers in the row of the option. For instance in option 1 it means that getting situation β is 10 times less important than getting situation γ.

**Figure 1.** Decision Support System to Select a Threshold for the use of Rapid DNA Analysis

**Derivation of the Formula used for Setting Thresholds**

The formula designed for this study based on RDT is derived in the following steps:

1) Decision $d_1$= rapid analysis; decision $d_2$ = no rapid analysis (but laboratory analysis)

2) True states $\theta_1$ = DNA profile, $\theta_2$ = no DNA profile

3) Denote a probability for a decision I and state j by $P_i(\theta_j)$. Probabilities to true states for $d_1$: $p_1(\theta_1)$ and $p_1(\theta_2) = 1\text{-}p(\theta_1)$ and for $d_2$: $p_2(\theta_1)$ and $p_2(\theta_2) = 1\text{-}p_2(\theta_1)$.

i) Because *$d_2$ = no rapid analysis* means laboratory analysis, the probabilities of obtaining a laboratory DNA profile (or not) are needed. It is assumed in this study that $p_2(\theta_2) = 0.15$.

4) Assign values $u(d_i, \theta_j)$ to the consequence of decisions in relation to the true states ($d_i$, $\theta_j$). The social values of the possible outcomes of the analysis decision are shown in Figure 1.

i) With the assumption: if Rapid DNA resulted in a DNA profile, laboratory analysis would also have resulted in a DNA profile.

5) Calculate the decision with the maximum expected $u(d_i, \theta_j)$. From a rational point of view, the decision with the highest expected value is

$$\bar{u}(d_i) = \Sigma_j\, u(d_i, \theta_j)\, p_i(\theta_j) \qquad (1)$$

i) With the assumptions: *1.* If a decision-maker opts for laboratory analyses and a DNA profile was obtained, the outcome of the Rapid DNA analysis is unknown (since Rapid DNA has a lower success rate). Therefore, in this situation it is assumed that the value for obtaining a DNA profile in the laboratory is independent of the hypothetical outcome of Rapid DNA; and *2.* If a decision-maker opts for Rapid DNA and no DNA profile is obtained, the outcome of laboratory analyses is unknown (due to a larger success rate for the laboratory analyses, a profile may have been obtained). Therefore, in this situation it is assumed that the value for not obtaining a DNA profile with Rapid DNA is independent of the hypothetical outcome of a laboratory analysis.

6) If positive values are chosen for all of the parameters in the calculations of expected values according to Eq. (1), we must assign a negative sign to α and δ in the formulae to indicate their adverse, negative outcomes: no DNA profile.

The following table summarises the above calculations:

| | **True state $\theta_1$: Profile** | **True state $\theta_2$: No profile** | **Expected values (weight)** |
|---|---|---|---|
| **$d_1$ rapid** | γ | -α | $u_{d1} = \gamma\, p_1(\theta_1) - \alpha(1 - p_1(\theta_1)$ |
| ***$d_1$ probability*** | $p_1(\theta_1)$ | $p_1(\theta_2) = 1\text{-}\, p_1(\theta_1)$ | |
| **$d_2$ no rapid** | β | -δ | $u_{d2} = \beta\, p_2(\theta_1) - \delta(1\text{-}\, p_2(\theta_1))$ |
| ***$d_2$ probability*** | $p_2(\theta_1) = 1\text{-}\, p_2(\theta_2)$ | $1\text{-}\, p_2(\theta_1) = p_2(\theta_2)$ | |

8) Then, when we apply RDT $\bar{u}(d_1) > \bar{u}(d_2)$ the formula can be deduced to:

$$\gamma\, p_1(\theta_1) - \alpha\,(1\text{-}\, p_1(\theta_1)) > \beta\,(1\text{-}\, p_2(\theta_2)) - \delta\, p_2(\theta_2))$$

solving for $p_1(\theta_1)$ gives

9) $(\gamma + \alpha)\, p_1(\theta_1) > \beta + \alpha - (\beta + \delta)\, p_2(\theta_2)$

$$\mathbf{P_1(\theta_1) > \frac{\beta + \alpha - (\beta + \delta)\, p_2(\theta_2)}{(\gamma + \alpha)}} \quad \textit{(when } \gamma + \alpha \textit{ is positive; being so by definition)}$$

## 8.3 Materials and Methods

### 8.3.1 Experimental Set-up

*Testing variables*
In order to analyse the influence of a DSS on deciding to analyse DNA traces rapidly at the crime scene or to forward the samples to the laboratory, a vignette experiment was designed. Participating SoCOs were taken through a crime scene on paper. In the set-up of this experiment, the following three independent variables were examined to determine if they influenced the decision to use Rapid DNA analysis:

1. Crime type: homicide or burglary
2. Trace type: ski mask or fabric glove
3. Time pressure: serial or singular

Other variables such as the quantity of traces, perpetrator-relatedness of the traces, and laboratory DNA success rates of the traces remained constant.
For the purpose of analysing the testing variables when Rapid DNA analysis is an option, comparable homicide and burglary cases were designed that were presumed to be either a serial or a singular case, where a Rapid DNA analysis decision on both a mask and glove trace had to be made.

*DSS – calculating the threshold value*
The threshold value for Rapid DNA analysis, calculated by using the DSS, is influenced by the laboratory DNA success rate. For this reason, to determine the effect of the variable 'trace type' in the experiment, two traces were chosen with comparable laboratory DNA success rates but different Rapid DNA success rates. This resulted in using a 'ski mask' with a laboratory DNA success rate of 90% and a 'fabric glove' with a laboratory DNA success rate of 80% (23). This difference in laboratory DNA success rates did not influence computing the numerical threshold values through the DSS and was therefore considered a constant. When using these different probabilities for obtaining a negative laboratory result (0.1 for the ski mask or 0.2 for the fabric glove), there appeared to be a negligible influence of the laboratory DNA success rate on quantifying the Rapid DNA analysis threshold; therefore, this probability was set to: $p(neg\_lab) = 0.15$.

*The crime scenes*
The burglary and homicide cases presented in this experiment were created based on actual crime scenes. To compare the cases, they were designed in such a way that they can be considered similar. In both cases, the crime scene investigation showed that the

lock on the door was forced and the apartment was turned upside down. Jewellery had appeared to have been stolen; and when searching for evidence, it was found that the perpetrator most likely wore gloves, as many smudged prints were noticed on items. This lead to the collection of the following traces:

1. **Print,** from dresser, potentially from a glove
2. **Tool marks**, at the door from breaking open the lock
3. **Ski mask**, sampled from the inside, around the mouth area

The homicide case was presented as a burglary gone awry when the owner came home during the burglary, and was killed by the burglar, leading to the collection of the following additional traces:

4. **Blood**, (most likely the victim's), sampled from the pool of blood where the victim was found. There were no additional blood spatters that indicated that the perpetrator might be injured.
5. **Wallet**, with smudge of blood (most likely the victim's)
6. **Clothes from the victim**, the Medical Examiner's office secured the victim's clothes. Most of them contain bloodstains (most likely the victim's).

Additionally, all the participants received the information that it was reasonable to assume that the perpetrator fled the scene, left the ski mask, and that this trace was the only perpetrator related DNA trace. It was also made clear that there was no reason to believe that the case was either a pattern burglary, or a serial homicide. Subsequently, the participants had to decide to use the Rapid DNA device or to forward the DNA sample to the laboratory, and had to explain their decision in detail.
Whether the participants chose rapid analysis or forwarded the sample to the laboratory, everyone received the information that unfortunately the sample did not result in a DNA profile and therefore could not be compared to the DNA database. They were informed that this result was a *correct* negative result, meaning that with standard DNA analysis procedures at the laboratory, the same result would have been obtained as with a rapid device.

Additional new investigative information was provided that a partner SoCO discovered a fabric glove near the apartment building. Because it was 21$^{st}$ July, mid-summer, finding a glove outside could be considered odd. The partner therefore collected and secured the glove and handed it over. The participants were further informed that the glove had a similar pattern to the print marks found on several items at the crime scene. It therefore fit the hypothesis that the perpetrator wore this particular glove while committing the crime. Again the participants were asked if they would analyse the

sample, this time from the inside of the glove, with the mobile Rapid DNA device and to explain their decision in detail.
Similar burglary and homicide scenarios were written with the addition of time pressure. The burglary case was designed as a pattern burglary and the homicide case was designed as a serial killing.

*Experimental conditions*
To examine whether a DSS would influence the decision to use Rapid DNA, and how this decision is affected by the testing variables three experimental conditions were conducted:

1. Control group: participants worked under standard protocol without any additional information
2. Success rate (SR) group: participants were provided with additional information on DNA success rates
3. Decision support system (DSS) group: participants were guided through the decision-making process of analysing a DNA trace, including using information on DNA success rates.

For the DSS, information on DNA success rates is required. To account for the potential influence of the DNA success rate information on the decisions in the DSS group, the SR group was added. This made it possible to analyse any effects of the provided DNA success rate information on the Rapid DNA analysis decision, and any additional effects of the DSS on this decision.

*DNA success rates*
Because the testing variable 'trace type' is incorporated in the study, laboratory DNA success rate knowledge is an important factor. Therefore, a DNA success rate questionnaire was designed to test the prior knowledge of the participants on this aspect. For this reason, the participants in the SR and DSS group had to fill out this questionnaire at the beginning of the case study. In this way, questionnaire findings were not influenced by the DNA success rate information of the ski mask and fabric glove trace they obtained during the experiment. Participants in the control group are considered the baseline. They received this questionnaire on DNA success rates at the end of the experiment, to prevent influences of this questionnaire on their decision-making process.

*Participants*
A total of 91 experienced SoCOs from the New York City Police Department participated in the study, of which there were 46 Detectives from the Crime Scene Unit

(CSU), and 45 Officers from the Evidence Collection Team (ECT). CSU Detectives typically investigate crime scenes where a victim is likely to die, whereas ECT Officers typically investigate high volume crimes. For this reason, the ECT participants performed the burglary experiment and the CSU participants performed the homicide experiment.
In total the participants consisted of 63 males and 28 females. The participants had an average age of 40 years old, 6 years of experience as a SoCO and 15 years of experience at the NYPD. There were no differences on these background variables between the ECT and CSU participants. However, the degree of education appeared to be significantly different, the ECT participants were significantly higher educated than the CSU participants. For this study all participants were equally divided and randomly assigned into the three experimental groups (DSS, SR and Control). In this case, there were no differences in background variables between the three experimental conditions.

*Experimental design*
The experimental design is shown in Figure 2. All participants were equally divided over the three experimental conditions (Control, SR and DSS). The participants in each condition either processed a homicide or a burglary case. In addition, *within* each case there were variations; each participant completed a case with time pressure (a serial burglary or homicide), and a similar case without time pressure (a singular burglary or homicide). In both of these cases, each participant had to decide on using Rapid DNA analysis for the ski mask trace and the glove trace. In this way all participants had to decide four times either for or against the use of a Rapid DNA device (2 trace types, and 2 case variations). The participants in the DSS group first had to decide on a threshold before making the Rapid DNA decision on the traces. In this way all DSS participants had to decide two times on a threshold.
To account for the potential sequence effects, half of the participants started with a serial case and the other half with a singular case.

### 8.3.2 Experimental Procedure

The experimental groups followed a strict experimental procedure as outlined in Figure 3. All participants received general information about the experiment, information on the Rapid DNA device and information on the case. The control group is considered the baseline and had to decide for or against Rapid DNA analysis within the cases, solely through the general information provided. Participants in the SR group received information on DNA success rates in addition to the general information, prior to making decisions on Rapid DNA analysis. The DSS participants were guided through the Rapid DNA decision-making process, on top of receiving additional DNA success rate information prior to opting for Rapid DNA analysis.

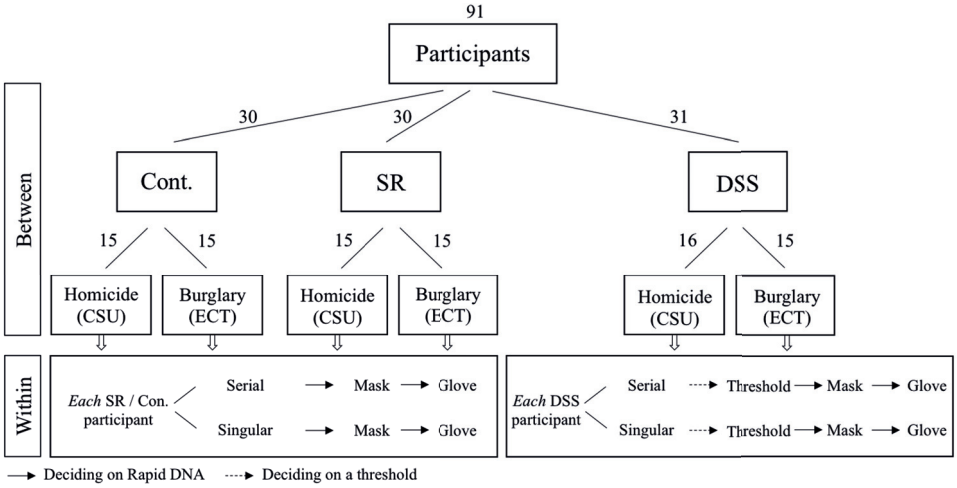



**Figure 2.** Experimental Design

All participants had to fill out a DNA success rate questionnaire; participants in the SR and DSS group filled out this questionnaire at the start of the experiment and participants in the control group at the end of the experiment.

*Briefing*

The participants were informed that they were part of a study regarding the use of mobile Rapid DNA devices at the crime scene. It was emphasised that this was not a test and there were no right or wrong answers, that they are the experts we wanted to learn from and that the results of the study would be handled anonymously.

*Introduction on Rapid DNA analysis*

The participants were told that the Rapid DNA device contains all the DNA analysis steps integrated into one system and that to use this device the DNA evidence needs to be sampled at the scene (additional training in the future) before the DNA sample can

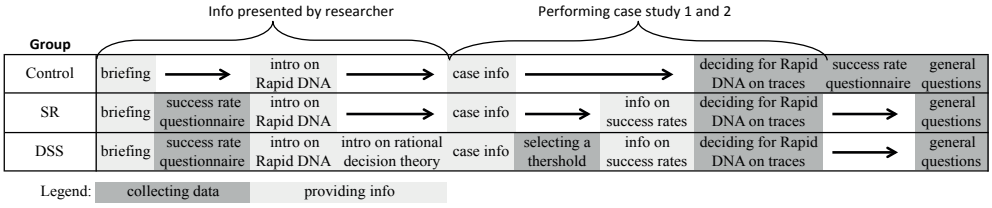



**Figure 3.** Experimental Procedure

be inserted in the Rapid DNA instrument. It was further explained that when a DNA profile is obtained, an automatic search of the Combined DNA Index System (CODIS) is performed. The use of the Rapid DNA device could therefore result in feedback on the sampled evidence within two hours. The device can be used for all types of DNA samples, as the evidence would be swabbed and the swab would be inserted into the instrument. Finally, participants were informed that Rapid DNA is less sensitive than laboratory analysis and the sample would be consumed, that results from Rapid DNA analysis could identify a suspect within two hours, compared to on average 45 days at the laboratory, and that a DNA profile obtained with Rapid DNA would be acceptable in court.

*Case information*
All participants received the case and were instructed to assume they were the assigned Detectives investigating the case, and therefore, they had to decide on using the Rapid DNA device for certain DNA samples. Participants were informed that the case was fictional but was created based on an actual criminal investigation; therefore, it also included the standard ambiguity and uncertainties associated with an actual case and performing a crime scene investigation. All information that was known about the case was provided.

*Deciding on Rapid DNA analysis*
The participants had to decide on the use of a Rapid DNA analysis on both the mask and glove trace. The participants were further instructed to describe their motivations behind their decisions in detail.

*Questionnaire on DNA success rates*
Participants were asked to assess the expected success of obtaining DNA profiles that could be used for comparison on a 7-point Likert scale; with 1 denoting an extremely low success rate, and 7 denoting an extremely high success rate.

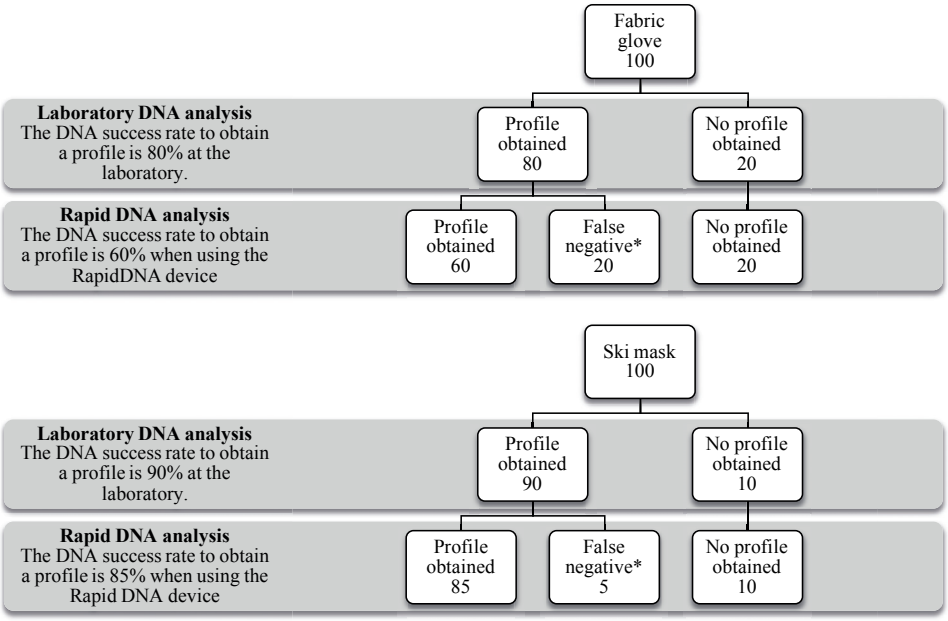
*Post-experimental general questions*
The experiment concluded with additional questions regarding DNA evidence, taking chances, taking risks, making decisions on the use of and operating the Rapid DNA device, cost analysis, benefit of a Rapid DNA device, and for the DSS group, the benefit of a Decision Support System.

*Information on DNA success rates in the DSS and SR groups*
Before making a decision to use Rapid DNA or laboratory analysis, participants in the DSS and SR groups were provided with additional information on the DNA success rates of a ski mask and fabric glove trace (Figure 4). The success rate for obtaining a

DNA profile when using the Rapid DNA device is 85% for the mask and 60% for the glove and when laboratory analysis is conducted the success rate is 90% for the mask and 80% for the glove[1].

*Introduction on rational decision theory for DSS group*

The DSS group was further informed that the use of Rapid DNA analysis has a 'time/success rate trade off', which meant that two dependent variables have to be considered when deciding to use the device. On the one hand is the time factor, as Rapid DNA analysis could accelerate the investigative process. On the other hand is the sensitivity factor (success rate), due to the Rapid DNA device being less sensitive than laboratory analysis, which means a potential risk of losing evidence when using Rapid DNA analysis. In order to use the DSS (which was developed to guide SoCOs in their decision-making), the basic elements of RDT were explained to the participants. Firstly, they had to choose a personal threshold fitting their case. Secondly, the participants had to decide on whether or not to apply Rapid DNA analysis, through the use of this threshold, along with information on DNA success rates.




** False negative means that the Rapid DNA device did not measure the actual profile because the quantity of DNA in the sample is below the threshold value of the device.*

**Figure 4.** DNA Success Rates of Ski Masks and Fabric Gloves, at the Laboratory and with Rapid DNA Analysis

[1] For this experiment we used simplified DNA success rates that were close to the actual DNA success rates (23) to make it more comprehensible for SoCOs.

The explanation of the RDT and the application of the DSS were explained with reference to a simple example of going to the theatre that night, and having to decide whether or not to bring an umbrella. In this example the result is 'rain' or 'no rain' in the given night, and the decision to bring an 'umbrella' or 'no umbrella' (Figure 5). These combinations result in four possible situations that can occur that night. There are two 'positive' situations (i.e. 'rain and umbrella' and 'no rain and no umbrella') and two 'negative' situations ('no rain and umbrella' and 'rain and no umbrella'). These situations each have specific consequences, and in order to proceed, these consequences need to be given a weight. A straightforward approach to defining these weights is by assigning numbers that are related to one another. For instance, the situation 'it rains and an umbrella is brought' has a positive consequence that we tentatively give the weight '1' to start. The other positive situation that 'it will not rain at night and no umbrella was brought' potentially has even more positive consequences (i.e, one does not get wet, but one is also not carrying an umbrella, etc.) and it could be decided that this is a two times better situation to occur than 'it rains and an umbrella is brought'. This implies assigning a weight of '2' to the situation 'no rain and no umbrella' (Figure 5).

Alternatively, a situation that is to be avoided would be 'no rain but an umbrella has been brought'. It has negative consequences because an umbrella that is not needed is carried all night. For instance, assigning this situation with a weight of '10' would mean that its consequences are 10 times more extreme compared to the consequences of 'it rains and an umbrella is brought', or 5 times more extreme compared to the situation of 'no rain and no umbrella'. The other negative situation, with intuitively the worst consequences, is 'rain and no umbrella is brought'. For instance, assigning this option with '20' implies that this situation has the most extreme consequences relative to the others.

By combining these assigned numbers for all situations (Figure 5) along with using RDT, a threshold of 36% was calculated. This would imply that, when the weather forecast gives a chance of rain greater than 36%, the most rational decision is to decide to bring an umbrella. Therefore, when the weather forecast gives a 30% chance of rain, the rational decision would be to *not* bring an umbrella (30% chance of rain < threshold 36%).

New situations produce new consequences and, in all likelihood, a different decision threshold[2]. For instance, when additional information is provided about wearing a $2000 suit or dress that night, which one prefers not to get wet, this would potentially make the consequences of 'rain and not having brought an umbrella' even more extreme. Changing the weight given to 'rain and no umbrella' to 100 would therefore result in a

[2] Please note the same situation may have different consequences for different individuals because the consequences are personal and consequently the decision threshold may differ.

threshold of 11%. Hence with a weather forecast of 30%, the rational decision would be to *bring* an umbrella (30% chance of rain > threshold 11%)[3].

You are going to the theatre tonight.
Will you take an umbrella with you?

| Result / Decision | Rain | No rain |
|---|---|---|
| Umbrella | **1** | **10** |
| No umbrella | **20/100** | **2** |

*The numbers are all related to each other*

*Results in threshold 36% / 11%*

**Figure 5.** Simple Example Explaining the Decision Support System

The example described above was used to explain how assigning numerical weights work to reach a personal threshold value, which allows decisions to be made on the use of Rapid DNA analysis in a criminal case. In the case under consideration, information was provided regarding a homicide or burglary crime scene, in which one DNA sample was collected that could lead to the perpetrator. The Decision Support System, as described in paragraphs 2.2.1, was further explained to the participants. The participants in this study were taken through all four options before using the threshold, in combination with the DNA success rate information, to make the Rapid DNA decision in their case study.

*Selecting a threshold in the DSS group*

In the first case, information on determining a threshold was provided. Subsequently the participants received the calculated threshold that accompanied their chosen option, 39%, 54%, 72% or 93% (Figure 1). It was made explicit that RDT suggests that for a certain DNA sample, the decision to analyse the DNA sample with the Rapid DNA device should be made when the probability of obtaining a DNA profile with Rapid DNA is larger than 39/54/72/93%[4]. The participants then performed a 'test' on how to use this threshold to decide whether or not to analyse a DNA sample with Rapid DNA analysis, when the DNA sample (in this case) has a 70% success rate of obtaining a DNA profile with Rapid DNA analysis. With thresholds 39% and 54% it would be

[3] If one would wear a suit that absolutely cannot get wet this implies one should always bring an umbrella. One could also choose to wear a different suit or travel in a different way but this would lead to a whole new decision process which we will not address here.

[4] Note that the calculated success rate threshold for Rapid DNA is larger than the actual success rate for laboratory DNA which was set at 85%. It may be assumed that actual success rates for Rapid DNA will always be smaller than actual success rates for laboratory DNA. Therefore, when the calculated threshold is 93% the decision-maker will always opt for laboratory DNA, irrespective of the performance of Rapid DNA.

rational to decide to *use* the Rapid DNA device; whereas, with thresholds 72% and 93% it would be rational to decide *not to use* Rapid DNA, and to forward the sample to the laboratory. Before proceeding to the next step, the participants were asked if they were satisfied with the given threshold. If the participants were unsatisfied, they had to manually change their threshold based on a scale of 1% to 100%; in addition, they had to rate the four situations based on their manually chosen threshold. From that point forward the manually chosen threshold was applied.
In the second case, the time pressure of the case changed and the participants were asked if they were still satisfied with their previously set threshold. When unsatisfied, the procedure to select a threshold was repeated.
In all decision steps, the participants were asked to describe their motivations behind their given answer in detail.

## 8.4 Hypotheses and Assumptions

To test if SoCOs' decision-making can be enhanced with the developed DSS, we tested the effect of the variables 'crime type', 'trace type' and 'time pressure' on deciding to use the Rapid DNA device on traces within the three experimental conditions. It was expected that SoCOs, who will be guided to think explicitly about the impact of their decision, will:

1) value the significance of the crime as higher within a serious case, putting more emphasis on avoiding false negatives in these cases. Therefore, opting to use the Rapid DNA device more often in a burglary case compared with a homicide case.
    a. Thus, higher thresholds are expected in a homicide case compared with a burglary case.
2) value the sensitivity of the Rapid DNA device higher for more successful DNA traces, leading to the decision to use the Rapid DNA device on the mask trace more often than the glove trace.
3) value the time sensitivity within the case as more important when the case experiences a time pressure, leading to more Rapid DNA analysis decisions in a serial type case compared to a singular type case.
    a. Thus, lower thresholds are expected in a serial case compared with a singular case.

In addition, we expect the SoCOs in the control and SR group to value the significance of the crime as higher within a serious case (see Hypothesis 1a).
SoCOs in the SR group also receive additional information on DNA success rates. It is therefore expected that the SoCOs in the SR group will also value the sensitivity of the Rapid DNA device higher for more successful DNA traces (see Hypothesis 2).

## 8.5 Results

### 8.5.1 DNA Success Rate Study

The participants had to assess the expected success rates of obtaining a DNA profile for several trace items on a 7-point Likert scale. We further categorised this scale as: 1-2 = low, 3-5 = moderate, and 6-7 = high chance of obtaining a DNA profile. The expected success rates for obtaining a DNA profile, as rated by the participants, were then compared to the actual success rates; these actual success rates were unknown to the SoCOs during this study (23).

Participants in the three experimental conditions showed no difference in rating DNA success rates of several samples. The results of the most frequently analysed samples are shown in Figure 6. This Figure indicates that actual DNA success rates do not always correspond with the participant's expectations, especially when the actual DNA success rates are low. In these instances, the participants less accurately assessed the success rate of obtaining a DNA profile. A zip tie, for instance, has an actual success rate of 15%, meaning that in 15% of the zip tie samples analysed at the laboratory a DNA profile is generated. However, almost all participants (95%) rated the zip tie trace incorrectly as a relatively successful trace (high and moderate combined) in obtaining a DNA profile.

All participants correctly rated the ski mask trace as a successful trace, 75% considered the trace as a highly successful trace and the remaining 25% considered the trace as a moderately successful trace in expecting to obtain a profile. For the fabric glove the majority of the participants (95%) expected the trace to have relatively high success rate (high and moderate combined), this roughly coincides with the actual success rate of almost 80%. Therefore, we generally considered the participants to have relatively sound baseline knowledge on *laboratory* DNA success rates for the traces used in this experiment, namely the ski mask and the fabric glove.

### 8.5.2 Deciding on Rapid DNA Analysis

#### 8.5.2.1 Quantitative Results

Each participant had to decide four times on the use of a Rapid DNA device. To account for the fact that we have this repeated measure on the binary dependent variable 'use of Rapid DNA', a Generalised Estimating Equation (GEE) was performed using the software SPSS (24). Because the goal of this experiment was to study the possible effects of 'crime type', 'trace type' and 'time pressure' on the use of Rapid DNA within the three group conditions (control, SR and DSS) the GEE was performed within each of these conditions.

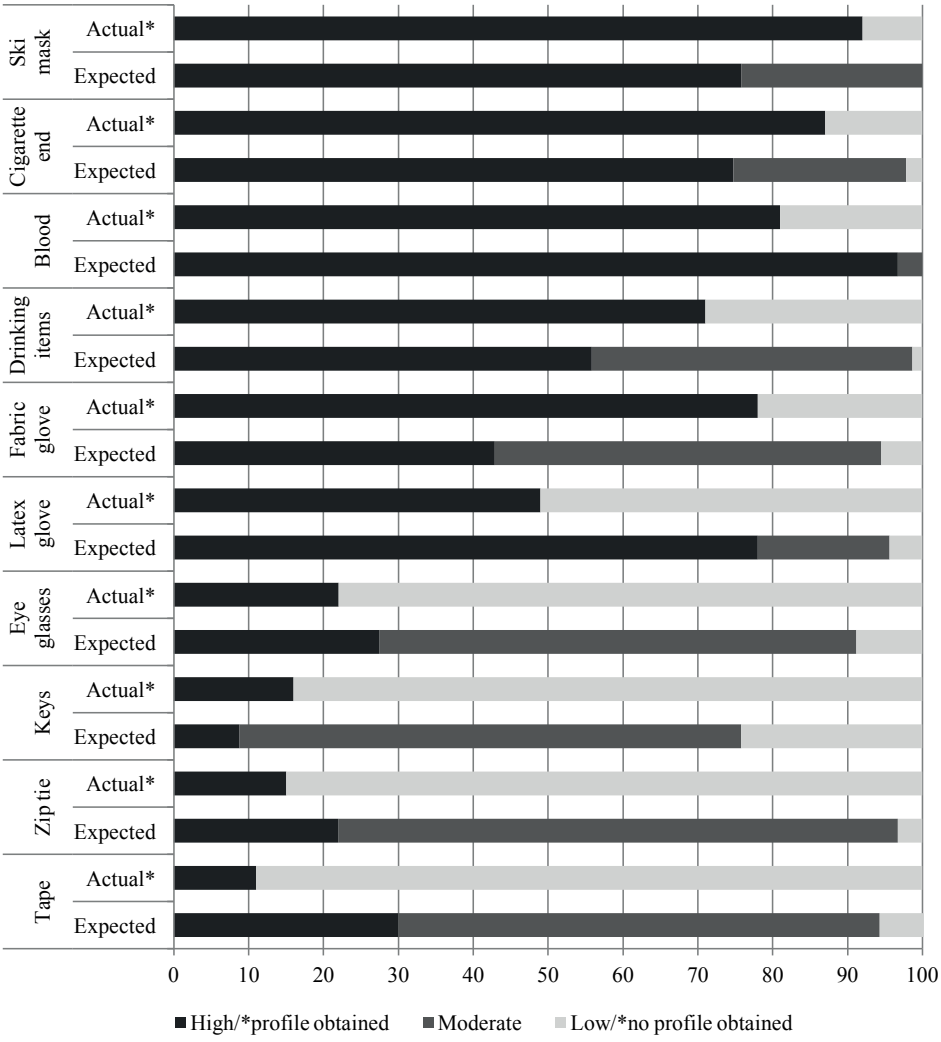



**Figure 6[5].** Expected Success Rates for Obtaining a DNA Profile versus the Actual Success Rates (23)
Traces are ranked from highest to lowest *actual* success rates.
The *actual* success rate scale shows the probability of obtaining (any kind of) DNA profile or no profile. The *expected* success rate scale shows the percentage of participants rating the trace on a 7-point Likert scale, we consider 1-2 as low, 3-5 as moderate and 6-7 as high.

[5] A comparable study on DNA success rates was performed with Dutch SoCOs (10).

*Sequence effect*

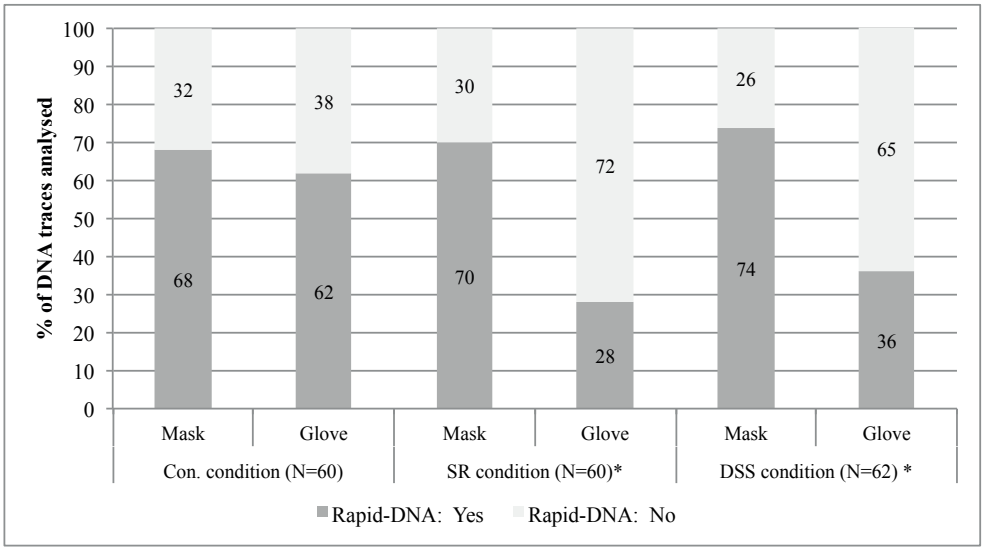
The GEE-model showed no sequence effects: the decisions to use a Rapid DNA device did not differ depending on the order of the cases within the three groups. This factor was therefore not taken into account for subsequent data analysis.

*Crime type*

Contrary to our expectations, using the same GEE-model, no difference for the variable 'crime type' within each of the group conditions was observed. This suggests that dealing with either a homicide or a burglary does not influence the decision to use Rapid DNA analysis on a trace. For this reason, the results of the use of Rapid DNA analysis from the comparable burglary and homicide case were evaluated together in subsequent analysis.

*Trace type*

Figure 7 shows the differences in deciding to analyse either a mask or a glove trace with Rapid DNA analysis. This Figure illustrates that the number of mask samples analysed with Rapid DNA was considerably higher compared with the number of glove samples rapidly analysed in the SR and DSS groups. Within the control group this difference is not observed, where deciding for Rapid DNA analysis on the mask or glove was roughly the same. This Figure also indicates that participants in the control group decided to




** Significant difference in analysing DNA traces rapidly between a mask and a glove ($p < 0.001$)*

**Figure 7.** The Influence of 'Trace Type' (Mask vs. Glove) on the Decision to use Rapid DNA Analysis within the three Conditions: Control, Success rate, and Decision Support System

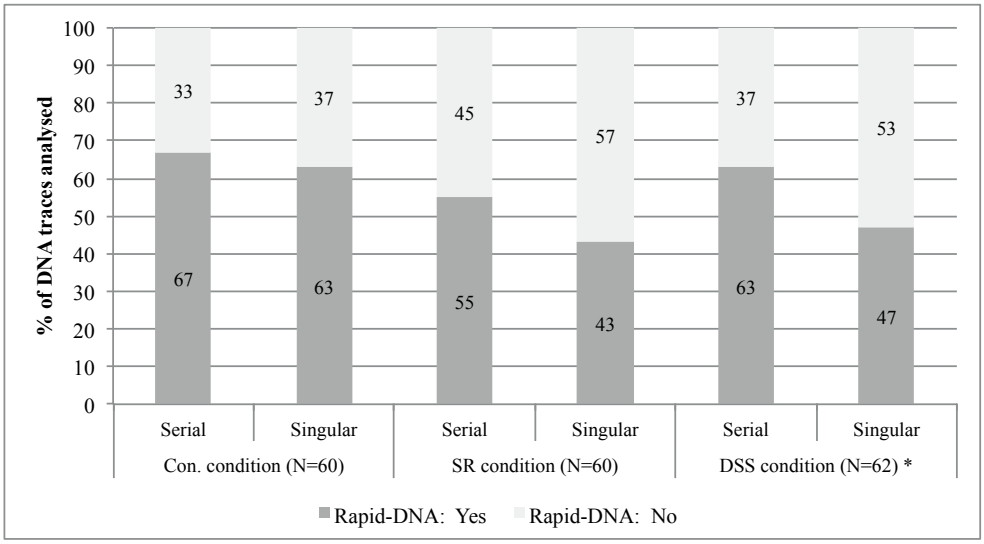
rapidly analyse a glove sample twice as often compared with participants in the SR or DSS group. This suggests that the participants in the SR and DSS groups are more hesitant to use Rapid DNA analysis on a trace with a lower DNA success rate.

Using the GEE-model within each of the conditions showed the same effect. Participants decided to use Rapid DNA analysis significantly more on the mask trace than on the glove trace in both the SR group ($B = 1.78$, Chi-square = 18.52 ($df = 1$), $p < 0.000$) and the DSS group ($B = 1.66$, Chi-square = 13.90 ($df = 1$), $p < 0.000$). The associated odds ratios showed that within both the DSS group and the SR group, participants were almost 6 times more likely to decide to use Rapid DNA analysis for the mask trace than for the glove trace.

The above results, therefore, indicate that not only guiding SoCOs with a DSS, but also merely providing information on DNA success rates, influences the decision to analyse a specific DNA trace with Rapid DNA analysis.

*Time pressure*

Figure 8 shows the results of deciding to use Rapid DNA analysis in a case with, and without, time pressure. The Figure indicates that within the control condition the decision to analyse a trace rapidly is independent of the time pressure (serial or singular) associated with the case. Within the SR condition there is a tendency to use the Rapid DNA device slightly more often within a serial case than in a singular case, but the variable 'time pressure' did not reach a significant effect within this condition. In the




** Significant difference ($p < 0.05$) between a serial case and a singular case in analysing DNA traces rapidly*

**Figure 8.** The Influence of 'Time Pressure' (Serial vs. Singular) on Deciding to use Rapid DNA Analysis within the three Conditions: Control, Success Rate and Decision Support System

DSS condition the participants decided significantly more often to use the Rapid DNA device within a case that is time-sensitive compared to a similar case that is not time-sensitive (performing a GEE-analysis B= 0.66; Chi-square=5.73 (df=1), p = 0.017). The odds ratio tells us that, within the DSS group, participants were almost two times more likely to decide for using Rapid DNA analysis in a serial case, where time pressure plays a larger role, compared with a singular case. This indicates that the time pressure associated with a criminal case influences the decision to analyse traces with a Rapid DNA device when SoCOs are guided through rational decision making with the use of a DSS.

#### 8.5.2.2 Qualitative Results

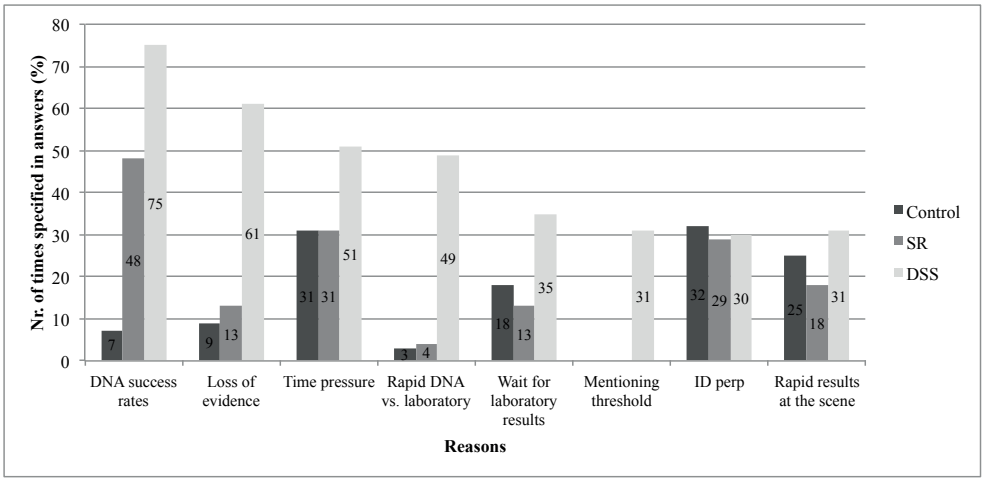
All participants described the motivations behind their decisions to either use Rapid DNA, or to forward the sample to the laboratory for analysis on the traces. In addition, participants in the DSS group had to describe their decisions on the chosen threshold prior to deciding to use Rapid DNA analysis. These specified decisions also determine the decision on using Rapid DNA analysis and were, therefore, combined in the analysis for the DSS group.

All specified decisions were analysed taking the following factors into consideration: 'DNA type', 'wait for laboratory analysis (safer / better / more reliable / controlled environment)', 'loss of evidence (consuming the sample)', 'DNA success rates', 'limited evidence (only one piece)', 'ID the suspect/provide a lead', 'time pressure', 'rapid results at the crime scene', 'weighing options - Rapid DNA vs. laboratory', and 'glove not found at the scene'. In addition, the factor 'mentioning the threshold' was taken into account for understanding decisions on threshold selection.

Taking all participants together (Control, SR and DSS), the main reasons to decide for Rapid DNA analysis were the DNA success rate of the trace (43%), the time sensitivity of the case (38%), the importance of identifying the suspect (30%), the risk of losing evidence (28%), and getting results rapidly at the crime scene (25%). For instance, a participant in the control group stated: *"Ski mask left by suspect has a high probability of skin cell DNA being present on the item and sufficient quantity to make a profile with which to identify the suspect. Suspect is likely to strike again based on the info available. Use of Rapid DNA device may lead to quicker apprehension of suspect and less loss of life."*

However, clear differences were observed between the three experimental conditions on their reasoning to decide for Rapid DNA analysis as shown in Figure 9. On average, the control and SR group participants rationalised their decisions with two reasons, whereas the DSS group participants rationalised their decisions with four reasons on average.

The control group showed no strong pattern in justifying their Rapid DNA decisions, mainly mentioning the time pressure of the case (31%), the importance of identifying the perpetrator (32%) and desiring rapid results at the scene (25%).




*Note that participants could state multiple options*

**Figure 9.** Qualitative Data on Deciding to use Rapid DNA Analysis on the DNA Traces.

The participants in the SR group showed a similar pattern. In addition, they used DNA success rates overall as a reason in 48% of the cases. This factor was considered as a reason to use Rapid DNA analysis (39%): *"The Rapid DNA analysis has an 85% success rate and it will cut down the time in which a result would come back significantly. I would rather that than wait for results from the lab"*. But, DNA success rates were considered more often when deciding *not* to use rapid analysis (56%): *"In this case I would send the sample to the lab even with the long turnaround time the probability of the mobile DNA analysis getting a profile is only 60% with 20% false negative, the lab has 80% success rate. A 20% reduction in the probability of a match is just too high"*.
The control group only mentioned DNA success rates in 7% of the times. However, this factor was never mentioned as a reason *not* to use Rapid DNA analysis and only rarely when using rapid analysis (10%): *"The rationale is that it was probably worn by the suspect, and for a decent amount of time. Definitely long enough to leave substantial DNA on the inside of the mask"*.
The participants in the DSS group, on the other hand, showed a much stronger pattern justifying Rapid DNA decisions (Figure 9). They relied on DNA success rates as a reason to a higher extent (75%), either to use Rapid DNA analysis: *"The DNA success rate obtained when a ski mask was processed with Rapid DNA analysis was only slightly lower than if the item was sent to the lab"* or not to use Rapid DNA analysis *"If there is a greater likelihood of success with traditional analysis when compared to Rapid DNA analysis in this case I would choose to send the glove for traditional DNA lab analysis."*
In addition, the DSS participants often discussed the risk of losing evidence (61%), especially when deciding not to use Rapid DNA analysis: *"Submitting the sample to the*

*lab. The success rate is 5% higher and the lab does not necessarily consume the sample submitted. In this case with only one DNA sample sending it to the lab is a safer option."* Although the majority of the participants in the DSS group relied on DNA success rates to decide on rapid analysis, the use of the threshold was explicitly mentioned in 31% of the cases: *"Because my threshold was 39% and the success rate was 85% the rapid method of DNA testing should be used to obtain a profile for this single burglary"* or: *"I would send the glove to the police lab, as it probably belongs to the perpetrator and there is only a 60% success rate with the Rapid DNA device (my threshold is at 70%).*
Overall, an important reason stated was the time sensitivity of the case (38%). However, the time sensitivity of the case was noted considerably more often by the DSS participants (51%) compared with the participants in the control group (31%) or the SR group (31%). When dealing with a *serial* case the DSS participants mentioned this factor (time sensitivity) to a larger degree as a reason to decide for Rapid DNA analysis (64%): "*Perpetrator is believed to be a serial killer. A rapid analysis of DNA should be conducted to avoid additional victims being killed",* whereas in a singular case the time pressure factor was less often discussed and mostly used to reason that there was no 'rush' in analysing a trace rapidly because there was no indication of a pattern and thus no time pressure (42%): *"Because this appears to be a lone case burglary I would elect to send the item to the lab, time is not of the essence in this case".*
Also, the participants in the DSS group often explicitly compared the Rapid DNA option with the laboratory option (49%) before making a decision: *"The success rate of Rapid DNA vs. laboratory is very close. I would think that the swift closure and capture of the serial killer would outweigh the extra 5% of success considered it comes at a cost of waiting 45 days."* This was rarely performed by participants in the control or SR group.
A final interesting observation was the mentioning of the glove found outside, not at the crime scene: *"Any identification from a piece of evidence found outside the initial crime scene would have a difficult time holding up in court."* This factor was only mentioned when deciding *not* to use Rapid analysis and was mostly mentioned by the control group (19%), somewhat less by the SR group (11%) and rarely by the DSS group (2%).

### 8.5.3 Selecting a Threshold

An important part of this study was designing and testing the use of the DSS based on Rational Decision Theory. For this reason, we discuss in more detail the effect of working with a DSS in a criminal investigation.

#### 8.5.3.1 Quantitative Results

The participants in the DSS group (N=31) were guided to explicitly acknowledge all possible decisions and the consequences of analysing a sample with Rapid DNA, or forwarding the DNA sample to the laboratory. For this reason, they had to set their personal threshold prior to deciding to use Rapid DNA analysis, within both a serial and

a singular case (performing either a burglary or homicide type case), resulting in a total of 62[6] selections across 4 possible thresholds: 39%, 54%, 72% or 93%.
To account for the fact that, again, we have a repeated measure, but now on the categorical dependent variable 'threshold', a GEE was performed using the software SPSS (24). The goal of this analysis was to determine the effects of 'crime type' and 'time pressure' for the thresholds.

*Sequence effect*
The GEE model showed no sequence effect in choosing a threshold. This means that deciding on a threshold is independent of evaluating a serial or a singular case first.

*'Crime type' and time pressure' effects*
Overall, threshold 39% was chosen 17 times, threshold 54% 10 times, threshold 72% 22 times and threshold 93% 12 times. There was no effect of 'crime type' or 'time pressure' on the selected thresholds for the use of Rapid DNA analysis. These results demonstrate that there are a wide variety of ideas about which threshold best fits cases.

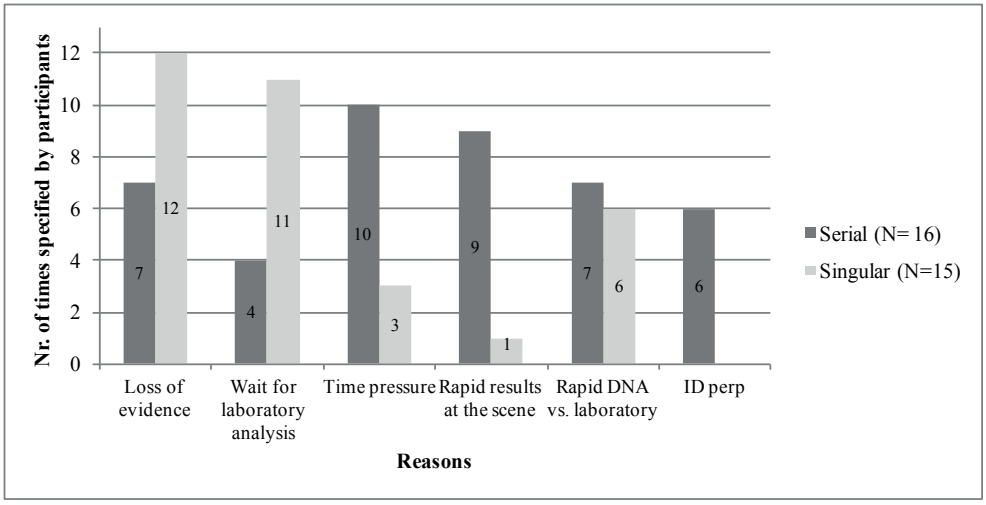
*Threshold switching from case to case*
Overall 80% (24/30[6]) of the participants in the DSS group did not change their threshold in the second case they had to evaluate; they continued using their first chosen threshold even though the time pressure in the second case changed. The six participants that did change their threshold either switched from a higher threshold in a serial case to a lower threshold in a singular case (2/6) or from a lower threshold in a serial case to a higher threshold in a singular case (4/6).

### 8.5.4 Qualitative Results

Utilising the first chosen threshold, the participants started with a test on using the threshold for making Rapid DNA analysis decisions. 29 out of the 31 DSS participants responded accordingly, and showed they understood how to use the theory for deciding on rapid analysis.
Only in the first case (either serial or singular) the participants had to deal with they had to explain in detail why they chose one of the four options leading to the threshold. Due to this set-up we analysed the qualitative data on selecting one of the four options 15 times in a singular case and 16 times in a serial case. This qualitative data was analysed in the same way as the qualitative data analysed for deciding to use the Rapid DNA device in paragraph 5.2.3.

[6] An administrative error on the first threshold of one ECT participant occurred. The chosen option for a threshold was option C but threshold 72% was given back, therefore for the quantitative analysis this threshold was not taken into account. However, the participant was satisfied with this threshold and did not change it, therefore the subsequent results were taken into account for this participant.

Overall the participants mainly considered the following factors when choosing a threshold option to use for the Rapid DNA analysis decision: 'loss of evidence' (19/31), 'wait for laboratory analysis' (15/31), 'weighing Rapid DNA vs. laboratory' (13/31), 'time pressure' (12/31) and 'rapid results at the scene' (10/31).
However, even though the quantitative analysis showed no significant difference, there were clear contrasts in reasoning within a serial case compared with a singular case, as shown in Figure 10. For a singular case, the majority of the participants (11 out of 15) decided to wait for results and have the laboratory analyse the DNA sample. In addition, they also often mentioned sensitivity and/or the risk of losing evidence (12/15), for instance one participant wrote: *"Results obtained (possibly) after 45 days from the lab is vastly superior than obtaining results (positive or negative) quickly and consuming what DNA evidence you have collected."*
Within a serial case more than half of the participants (9/16) reasoned they preferred DNA results as fast as possible and/or considered the time pressure of the case (10/16), explained by one participant as: "*Being that this is a serial killer and we believe that he will keep killing until he is caught, it is important to ID him/her as soon as possible."*
However, four participants evaluating a serial case considered waiting for laboratory results to be the best option: *"No evidence from other crime scenes in this pattern. I would rather take the time to analyse through the lab than rush with rapid DNA."*
Whereas, just one participant mentioned wanting to obtain rapid results and use Rapid DNA in a singular case.
Although the factor 'losing evidence' was considered by the majority when dealing with a singular case, only 7 out of 16 participants in a serial case mentioned it. This led to emphasising laboratory analysis 3 times: *"You might lose evidence. So in some way it is better to get results after 45 days"* and in 3 instances the time pressure still prevailed: *"It is more important to make an early identification than the possibility of losing some potential DNA."*
Less than half of the participants in both the serial case (7/16) and the singular case (6/15) actually discussed and considered the laboratory option versus the rapid option when making a decision on a threshold option. For instance, within a serial case: *"Being that this is a serial killer and we believe that he will keep killing until he is caught, it is important to ID him/her as soon as possible. The problem would be that the only probative evidence in the case would be completely consumed by the Rapid DNA analysis. This is why I chose option 2. It recognises the importance of a fast turn-around but also puts weight to the possible destruction of key evidence."* and with a singular case: *"There is only one piece of DNA evidence that is related to the perpetrator. It is more important to have that sample analysed in the lab, even though it will take 45 days to have that sample available for additional testing, than it is to have the results within 2 hours and possibly losing the sample for additional testing.*




*Note that participants could state multiple options*

**Figure 10.** Qualitative Data on Deciding for a Threshold Option

### 8.5.5 Using the Thresholds

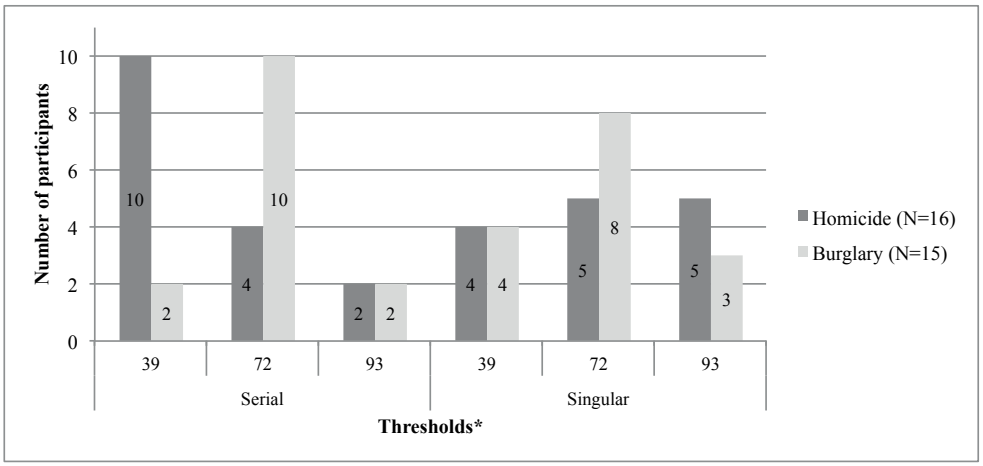
In the DSS group, even though an effect of deciding to use the Rapid DNA device was observed on the variables 'time pressure' and 'type of trace', half of the participants (16/31) made at least one decision for rapid analysis that did not correspond to their chosen threshold (this applied to 29 decisions in total). This occurred both in the first case (either serial or singular) and in the second case (either serial or singular) they dealt with. Based on RDT these decisions could be considered 'irrational'. Of these 16 participants, 15 correctly answered the test question on using RDT for deciding on DNA analysis. In addition, the previously analysed qualitative data showed that these decisions were well-reasoned and thoroughly through-out decisions. The threshold and/or the DNA success rates were explicitly discussed when opting against the chosen threshold on using the Rapid DNA device. For instance, a participant with threshold 54% on the glove chose not to analyse the sample whereas when considering this threshold the DSS suggests to analyse the sample rapidly: *"In this situation I would avoid the 20% false negative and take my chances with the 80% profile obtained at the lab"*.

The participants who decided, against their chosen threshold, to forward the sample for laboratory analysis mentioned it was safer and more reliable to opt against rapid analysis *"Even though the percentage is above 50% I think with the severity and importance of this case I would have the lab test the evidence because the labs success rate is 20% more effective."* In contrast the majority of the participants deciding against their chosen threshold to use Rapid DNA analysis reasoned that rapidly identifying the perpetrator is most important *"Analysing the glove with the rapid DNA would possibly lead to identifying a perpetrator in regards to these homicides. It is more important to identify*

*the perpetrator in this case quickly then to possibly get results from the lab at a later date."*

This raised the question whether we could find more 'appropriate' thresholds for the cases when considering 'fitting' thresholds for the 16 participants that decided against their chosen threshold for using Rapid DNA analysis. We analysed which thresholds they should have chosen, based on their given answers, and combined these with the thresholds of the 15 participants who correctly used the DSS. In this experiment, the two lowest thresholds should lead to the same results of using Rapid DNA analysis. However, the results show that when threshold 54% is chosen, all participants actually desired a higher threshold. Participants desiring a low threshold mostly chose the lowest threshold of 39%. There were three participants that chose threshold 93% or 72% but should have chosen a lower threshold, therefore we assigned threshold 39% to them. Figure 11 shows that threshold 54% disappears and a somewhat stronger pattern of thresholds is observed, especially when dealing with a *serial* homicide or burglary case. Participants handling a homicide appear to actually desire lower thresholds in a serial case, and higher thresholds in a singular case. For participants handling a burglary, it appears best to actually utilise threshold 72%.

The GEE analysis showed that the interaction of 'crime type' (homicide or burglary) and 'time pressure' (serial or singular), significantly influenced the fitting thresholds (B = -1.10, Chi-square = 7.52 (df = 1), p = 0.006). Within a *serial* case the threshold that best fits a homicide is 39%, whereas threshold 72% best fits a burglary. For a singular burglary case threshold 72% again seems to fit best, whereas no clear pattern of threshold selection is observed for the singular homicide case.




*Three times in the homicide group a fitting threshold was either 39% or 54%. Based on the results they were counted with 39%. In addition, it was decided to rapidly analyse the glove but not the mask, two times in the singular homicide case and one time in the serial burglary case. Based on our DSS this is not possible; therefore, no threshold fits.*

** Significant interaction ($p < 0.01$) of 'crime type' and 'time pressure' on the 'fitting' thresholds.*

**Figure 11. '**Fitting' Thresholds

### 8.5.6 Added Value of Rapid DNA and DSS

*Rapid DNA analysis added value for CSI*
More than 90% of the participants (85 out of 91) saw added value for using a Rapid DNA device in their investigative process. As stated by a few participants: *"It can possibly link DNA to a suspect in hours as opposed to days or months", "Quickly identifying a suspect can be critical to apprehension and possibly saving lives", "It's a great tool to expedite results. However, I would only use it when there are several pieces of evidence. Better results are more important than speedy results", "Could be useful tool when performing routine ECT jobs".*

*DSS added value for SoCOs*
The majority of participants in both the burglary (13/15) and the homicide (14/16) groups were very positive about the DSS, and saw added value in using RDT during decision-making when Rapid DNA analysis becomes available at the crime scene. Some statements of the participants on this matter: *"Decisions on where and when to use the Rapid DNA device should be made with 'risks' vs 'rewards' kept in mind." "With this DSS you can make decisions on a case by case situation. You can decide how serious or minor the crime is or how quickly you need to find the perp. Many factors can be combined whether to decide to use the Rapid DNA device or not." "Anytime you think about the possibilities/consequences on a crime scene and use common sense about what could have taken place, your investigation will proceed in a thought out and orderly fashion."*

## 8.6 Discussion

When the identification of perpetrators through rapid systems becomes a standard law enforcement practice, standardisation and error minimisation becomes crucial. When Rapid DNA analysis is operable at the crime scene, the desire to search DNA traces for rapid analysis to confirm hypotheses could potentially lead to overestimating the actual value of the information, or loss of potential informative DNA results. Therefore, it is fundamental that the process to decide to use a Rapid DNA device be accepted within the criminal justice system.
For this reason, it is essential that decisions are, preferably, not solely based on the thoughts, ideas and expertise of just one individual. A practical solution to (potentially) correct for human errors and biases may be a DSS for Rapid DNA analysis. In the current explorative study, a principal DSS was designed for this purpose, to be used by the SoCO at the crime scene. This study provides evidence for the fact that a systematic approach, which consists of weighing all possible outcomes before deciding to use a Rapid DNA analysis device, may assist SoCOs in their decision-making process. The

results demonstrated that participants made different, and more thoughtful, choices on analysing traces rapidly when explicitly acknowledging the effect of all possible outcomes, compared to participants who were not encouraged to weigh the different decision outcomes. The DSS we developed and tested for this study should be seen as a prototype, which could be customised with additional case specific information that could be considered in the decision to use a Rapid DNA device.

In this study, the effect of the variables 'crime type', 'trace type' and 'time pressure' were analysed on the decision to use the Rapid DNA device within three experimental conditions, namely the control group, the SR group and the DSS group.
Contrary to our hypothesis, there was no effect of 'crime type' (burglary or homicide) when deciding to use the Rapid DNA device. However, the group of participants deciding on burglary cases differed from the group of participants deciding on the homicide cases. The Crime Scene Unit participants from the NYPD processed homicide type cases, and the participants of the Evidence Collection Team only processed comparable burglary type cases. The results could indicate that CSU participants handle a homicide case in the same way as ECT participants handle a burglary case. On the other hand, it could be debated whether we actually examined crime type or the difference between CSU and ECT participants. To explicitly investigate 'crime type', future analysis should be performed with a more general population that is used to analysing both crime types. However, NYPD SoCOs either strictly deal with serious crimes, or more high volume crime type cases. For this reason, we cannot conclude whether or not a difference exists in handling a burglary or homicide case, when Rapid DNA analysis is an option, based on the current study.
To decide whether traces can be analysed with a rapid device, it is crucial to have knowledge on the likelihood that a trace contains sufficient DNA to generate a DNA profile. In this study the likelihood of obtaining DNA profiles from specific traces in the lab – the so-called '*laboratory* DNA success rate' – was considered basic knowledge. However, this study demonstrated that participants lacked awareness about the laboratory DNA success rates of many traces, especially of the low quantity DNA traces. Similar results were found in a study with Dutch SoCOs (10). In addition, the results of the current study showed that the control group did not use Rapid DNA analysis differently on the mask trace than on the glove trace. This is probably due to the fact that the participants in the control group were unaware of the different Rapid DNA success rates of those two traces, and therefore did not take into account the sensitivity of the rapid device, and its consequence for traces with a low success rate. In reality, NYPD SoCOs currently working in CSU and ECT do not receive feedback on their analysed traces. Therefore, they are not familiar with the results of the samples they submit for analysis and lack knowledge on DNA success rates. It is highly recommended that SoCOs obtain feedback on the results of the submitted samples and develop insight

on DNA success rates, especially when Rapid DNA is introduced.
The qualitative data support this conclusion, and revealed that DNA success rates were mainly considered by participants in the SR and DSS group before deciding to use Rapid DNA analysis. This resulted in deciding to use Rapid DNA analysis significantly more often on the mask trace compared to the glove trace. This was expected and indicates that knowledge on DNA success rates is necessary in making evidence-based decisions for Rapid DNA analysis.
Only participants in the DSS group showed an effect of the variable time pressure, and decided to analyse significantly more DNA traces rapidly within a serial case compared to a singular case. The qualitative data again support this finding, with participants in the DSS group accounting for time pressure considerably more often than participants in the SR or control group, and especially when dealing with a serial case. This suggests that there is an increase in taking risks for gains with the pressure of time, supporting more risk acceptance in time-sensitive cases (25, 26).
A final interesting finding is that the qualitative data on the motives underlying the decision to use the Rapid DNA device showed that SoCOs in the control group considered crime relatedness of the trace, even though this was presumed to be a given. Participants in the control group regarded 'finding the glove outside' as less crime related, potentially not holding up in court, and thus not material for Rapid DNA analysis. This was mentioned less in the SR group and rarely in the DSS group and could indicate that making decisions through a DSS should be handled with caution, especially when factors are not explicitly incorporated in the system. In this study only the three testing variables 'crime type', 'trace type' and 'time pressure' were incorporated into the model. This shows the importance of designing a flexible DSS that could be customised with additional factors in the future.

The fact that participants in the DSS group showed a stronger difference in deciding to use the Rapid DNA device, but also made more elaborate and thorough decisions, could be interpreted as an effect of using the DSS. In this condition, participants were explicitly guided to consider all possible outcomes and consequences, and in combination with information on DNA success rates, they had to decide on the use of the Rapid DNA device. These DNA success rates were essential for the use of the DSS as designed for this study. When the threshold to use the Rapid DNA device was below the Rapid DNA success rate of the specific trace, the DSS suggests it is 'rational' to choose immediate DNA analysis at the crime scene. It is important to determine whether universal baseline thresholds can be set for specific cases to assist in the decision-making process for Rapid DNA analysis. In this study, a greater variety was observed between individuals on what they consider an appropriate threshold.

The expectation of this study was that baseline thresholds could be extrapolated for specific cases. The goal of using a DSS is to make case-based decisions rather than individual-based decisions. An explanation for the variety of threshold choices could be the somewhat low sample size of 31 (16 homicide participants and 15 burglary participants). However, the 'new' concept of
assigning values to possible outcomes might also be considered a difficult task, which is of course a practical problem when trying to identify uniform thresholds. The method used to set values for these outcomes may not have been ideal, and it is a challenge to search for other methods that are more suitable for this purpose. More than half of the participants made Rapid DNA decisions that did not correspond to their chosen threshold. The elicitation of reliable values that can be used to set a threshold might be a difficult matter. One option is to determine a threshold on which several individuals may find intersubjective agreement (1, 12). Implicitly every decision-maker must utilise a certain threshold to deal with the 'time/success rate trade off' to finalise on the use Rapid DNA analysis (7). The future challenge is to agree upon the best-fitting uniform thresholds for several cases and create easy-to-use expert systems.
The qualitative data suggests that when evaluating a serial case, time pressure appears to be an important factor when choosing a threshold, and deciding for Rapid DNA analysis; whereas, within a singular case, the loss of evidence is an important reason to choose laboratory analysis more often, indicating that different factors are important to consider when deciding on a threshold in a serial and singular case. This, however, was not observed when looking at the chosen thresholds, possibly due to the fact that participants found it difficult to value the various outcomes, and to set their threshold. This might result in participants rationally deciding against their chosen threshold, because they became more aware of the effect of the chosen threshold when applying it in a concrete case. This could be seen as a form of 'latent rationality'.
When considering 'fitting' thresholds which correspond to the decisions the participants finally made, participants tended to desire the lowest thresholds in a serial case; whereas, as became clear from the qualitative data, they considered the time pressure more often as an important factor. When deciding on a threshold in a *serial* homicide case, more emphasis is placed on obtaining a rapid outcome, thus lower thresholds seem to fit better with these cases. In a singular burglary or homicide case, and a *serial* burglary case, participants tended to be more error-focused, placing more weight on avoiding (false) negative results, which leads to higher thresholds. This indicates that when a crime is more significant and serial, people tend to accept potential errors faster. The qualitative data support these results.
It is also important to realise that generally the process of deciding for Rapid DNA analysis could be guided by internal factors such as experience, confidence, state of mind and personality of the decision maker (27). This is also known as 'image theory', where decisions are made based on whether they fit personal values, goals and strategies

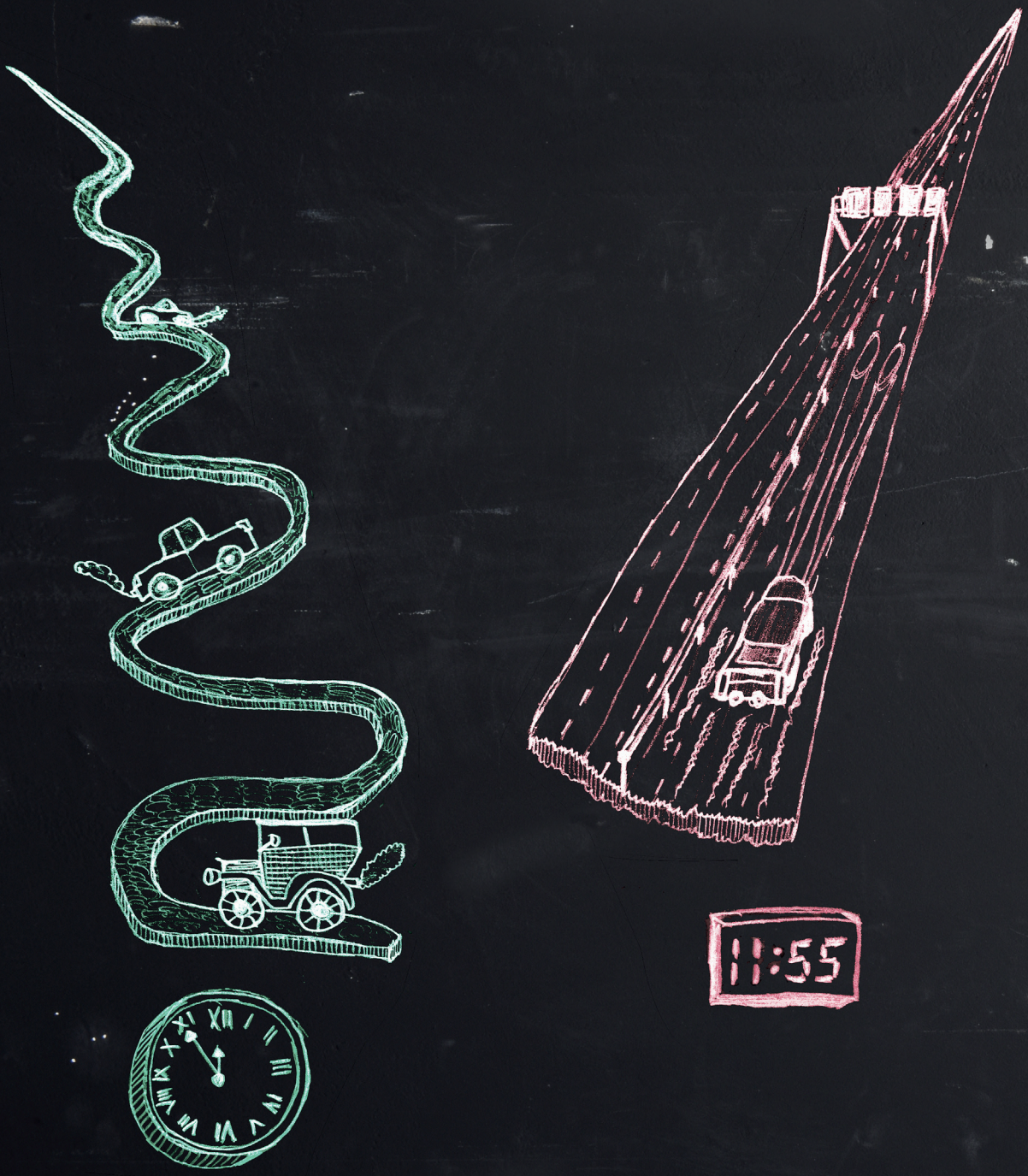
of the decision maker (28, 29). In criminal investigations, the internal factor 'emotion' may influence the decision to use Rapid DNA analysis, especially when the case is more serious and the "desire to see justice done" may be stronger (28, 30). Therefore SoCOs may have different preferences on choosing thresholds and using the Rapid DNA device for different types of crime, and they rationally follow their preferences (31). Collectively, this could explain the wide variety of thresholds chosen, and is worthy of future experimental study. Deliberate practice, where exercises are focused on improving particular tasks, involving immediate feedback, time for problem-solving and evaluation, with the opportunity for repeated performance, could refine behaviour and therefore rational decisions on choosing a threshold and using the Rapid DNA device may be attained (32). The path forward necessitates not only identifying fitting thresholds for several cases, but also educating SoCOs in operating crime scene investigations using a Rapid DNA device.
Integrating Rapid DNA technologies at the crime scene will result in adjusting current forensic procedures. In order for SoCOs to make accepted decisions, training will play a vital role in making the SoCOs aware of the cognitive processes involved in the perception of risk and decision-making, and therefore needs to be part of future CSI best practices (27). For the optimal use of Rapid DNA analysis, SoCOs have to be made aware of the existence of certain biases such as contextual and personal factors that could influence their decision (28). This study proposed the use of a DSS as a guide to systematically approach the decision problem of performing Rapid DNA analysis within a criminal investigation. The SoCOs appeared to be excited about integrating such a DSS into their CSI routine and see added value for making more reliable decisions when Rapid DNA analysis finds its way to the forensic crime scene.

In conclusion, while certain challenges still exist, this study provides positive evidence that integrating a DSS for the use of Rapid DNA analysis influences the decision-making process of analysing DNA traces at the crime scene. We believe this, therefore, to be an important step towards guiding the integration process of Rapid DNA analysis at the crime scene, to make effective and efficient decisions in the criminal justice system.

## 8.8 References

1. Parmigiani G, Inoue L. *Decision theory: principles and approaches*. West Sussex: John Wiley & Sons; 2009.
2. Blackman S, Dawnay N, Ball G, Stafford-Allen B, Tribble N, Rendell P, et al. Developmental validation of the ParaDNA® Intelligence System—A novel approach to DNA profiling. *Forensic Science International: Genetics,* 2015;17:137-148.
3. Holland M, Wendt F. Evaluation of the RapidHIT™ 200, an automated human identification system for STR analysis of single source samples. *Forensic Science International: Genetics*, 2015;14:76-85.
4. Mapes A, Kloosterman A, Poot de C, van Marion van V. Objective data on DNA success rates can aid the selection process of crime samples for analysis by rapid mobile DNA technologies. *Forensic Science International*, 2016;264:28-33.

5. Crime Scene Investigation: A Guide for Law Enforcement. 2000. Retrieved from: https://www.nist.gov/sites/default/files/documents/forensics/Crime-Scene-Investigation.pdf.
6. Bonnes J. *Pre-assessment of forensic investigations - A decision theory based model and its effect upon makers of decisions in legal matters*. Master thesis Psychology, Faculty Social Science University of Leiden. 2014.
7. Bonnes J, Vergeer P, Stoel R. Rationele besliskunde in het strafrecht - de sprong van bewijs naar beslissing. *Nederlands Juristenblad*, 2015;90(6):354-416.
8. He P, Tao W. A Design of Criminal Investigation Expert System Based on CILS. *Journal of Software,* 2011;6(8):1586-1593.
9. Kahneman D, Tversky A. On the psychology of prediction. *Psychological Review,* 1973;80(4):237-251.
10. Mapes A, De Poot CJ. Rapid DNA analysis at a mock crime scene - The impact on collecting and analysing DNA traces. Under review at *Journal of Forensic Sciences,* August 2017.
11. Yang J, Liu Y, Zhang Y, Chen H, Niu F. Escalation bias among technology entrepreneurs: the moderating effects of motivation and mental budgeting. *Technology Analysis & Strategic Management,* 2015;27(6):693-708.
12. Biedermann A, Bozza S, Taroni F. Decision theoretic properties of forensic identification: underlying logic and argumentative implications. *Forensic Science International,* 2008;177(2):120-132.
13. Connolly T. Decision theory, reasonable doubt, and the utility of erroneous acquittals. *Law and Human Behavior,* 1987;11(2):101-112.
14. Kaplan J. Decision theory and the factfinding process. *Stanford Law Review,* 1968;20:1065-1092.
15. Lindley DV. *Making decisions 2nd ed.* Chichester, England: John Wiley & Sons; 1985.
16. Biedermann A, Bozza S, Garbolino P, Taroni F. Decision-theoretic analysis of forensic sampling criteria using Bayesian decision networks. *Forensic Science International,* 2012;223(1):217-227.
17. Biedermann A, Bozza S, Taroni F, Aitken C. The consequences of understanding expert probability reporting as a decision. *Science & Justice,* 2017;57(1):80-85.
18. Taroni F, Bozza S, Aitken C. Decision analysis in forensic science. *Journal of Forensic Sciences,* 2005;50(4):JFS2004443-12.
19. Taroni F, Bozza S, Bernard M, Champod C. Value of DNA tests: a decision perspective. *Journal of Forensic Sciences,* 2007;52(1):31-39.
20. Dhami MK. On measuring quantitative interpretations of reasonable doubt. *Journal of Experimental Psychology: Applied,* 2008;14(4):353-363.
21. Biedermann A. The role of the subjectivist position in the probabilization of forensic science. *Journal of Forensic Science and Medicine*, 2015;1(2):140-148.
22. Eisenführ F, Langer T, Weber M. *Rational decision making*. Berlin: Springer - Verlag; 2010.
23. Mapes AA, Kloosterman AD, Marion van V, Poot de CJ. Knowledge on DNA success rates to optimise the DNA analysis process: from crime scene to laboratory. *Journal of Forensic Sciences,* 2016;61(4):1055-1061.
24. IBM Corp. Released 2012. IBM SPSS Statistics for Mav VA, NY: IBM Corp.
25. Dror IE, Basola B, Busemeyer JR. Decision making under time pressure: An independent test of sequential sampling models. *Memory & Cognition,* 1999;27(4):713-725.
26. Young DL, Goodie AS, Hall DB, Wu E. Decision making under time pressure, modeled in a prospect theory framework. *Organisational Behavior and Human Decision Processes,* 2012;118(2):179-188.
27. Dror IE. Perception of risk and the decision to use force. *Policing,* 2007;1(3):265-72.
28. Helsloot I, Groenendaal J. Naturalistic decision making in forensic science: toward a better understanding of decision making by forensic team leaders. *Journal of Forensic Sciences,* 2011;56(4):890-897.
29. Morrell K. Decision making and business ethics: the implications of using image theory in preference to rational choice. *Journal of Business Ethics,* 2004;50(3):239-252.
30. Pyrek K. *Forensic science under siege: The challenges of forensic laboratories and the medico-legal investigation system.* Academic Press; 2010.
31. Whitman G, Koppl R. Rational bias in forensic science. *Law, Probability & Risk,* 2010;9(1):69-90.
32. Anders Ericsson K. Deliberate practice and acquisition of expert performance: a general overview. *Academic Emergency Medicine,* 2008;15(11):988-94.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# Chapter 9

## The Interface Between Forensic Science and Technology[1]

*How technology could cause a paradigm shift in the role of forensic institutes in the criminal justice system*

**Abstract**

In this paper the importance of modern technology in forensic investigations is discussed. Recent technological developments are creating new possibilities to perform robust scientific measurements and studies outside the controlled laboratory environment. The benefits of real time, on site forensic investigations are manifold and such technology has the potential to strongly increase the speed and efficacy of the criminal justice system. However, such benefits are only realised when quality can be guaranteed at all times and findings can be used as forensic evidence in court. At the Netherlands Forensic Institute innovation efforts are currently undertaken to develop integrated forensic platform solutions that allow for the forensic investigation of human biological traces, the chemical identification of illicit drugs and the study of large amounts of digital evidence. These platforms enable field investigations, yield robust and validated evidence and allow for forensic intelligence and targeted use of expert capacity at the forensic institutes. This technological revolution in forensic science could ultimately lead to a paradigm shift in which a new role of the forensic expert emerges as developer and custodian of integrated forensic platforms.

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## 9.1 Introduction:
### The interface of science and technology in forensic science

Technology can be regarded as a vital catalyst in the transition of scientific findings and insights into innovation. Added value of science is materialised through technology enabling society to fully benefit from new discoveries. Such benefits are very diverse (e.g. health, economic, trade, transport, communication, sustainability, conservation of cultural heritage, safety, security and justice) but have in common that they raise the quality of life and provide progress and prosperity in societies (assuming that these benefits outweigh the potential misuse and threats that are also associated with new scientific findings). The cycle of science, innovation and growth is the rationale behind the very substantial and structural investment of developed countries in science programs. From this broad and generic perspective it is very interesting to take an in-depth look at the interface between technology and forensic science. Contemporary forensic institutes operate state-of-the-art laboratories were evidence is studied with modern instruments. Without this often high-tech and expensive equipment the forensic expert would not be able to generate the forensic findings that so often are of vital importance to solve a crime and assure high quality rulings in a court of law (1). Ideally new technology is made “fit-for-forensic-purpose” in such a way that accredited and efficient use in the forensic laboratory is enabled, evidential value is established and criminalistic interpretation is incorporated. Contemporary forensic STR DNA profiling is the most obvious and striking example of such a merger of scientific discovery, technological advancements and forensic application and interpretation.

At the Netherlands Forensic Institute (NFI) forensic innovation efforts are currently undertaken to create new forensic methods that can be broadly applied in the criminal justice system and do not only serve to increase the capability of forensic laboratories. Also outside the forensic domain new technological advances can be noticed in recent years that allow scientific data, information and insights to be obtained outside a controlled laboratory environment as is discussed in more detail in Paragraph 9.2. In “connecting the forensic laboratory to the scene” the added value can be greatly increased especially if field methods do not just generate indicative information but rather robust data and findings that can directly be used as evidence in court. Within the Dutch Criminal Justice System a huge gain in speed, efficiency and quality is anticipated especially for high volume cases with limited forensic interpretation (e.g. chemical identification of drugs of abuse or securing and classifying digital data). However, the regular use of forensic methodologies outside the controlled laboratory environment by untrained forensic experts requires substantial technological efforts. Quality of the findings must be guaranteed at all times, the equipment needs to function in a robust manner under variable and unfavourable conditions and must be very easy to operate. Only through technology such requirements can be met and efforts should be aimed at

automated forensic interpretation, reporting uncertainties and minimising potential errors by the operators. Wireless communication could form the basis of creating a forensic platform for quality assurance and central analysis of the data gathered by numerous field devices. This technological revolution in forensic science could lead to a paradigm shift in which a new role of the forensic expert will emerge as developer of evidence analysers and custodian of integrated forensic platforms. Forensic expertise and interpretation would then find its way in evidential value algorithms and quality control procedures that form the basis of the forensic field methodology. In the criminal justice chain this ultimately could lead to a shared interdisciplinary forensic platform allowing the rapid and very efficient investigation of evidence first hand by case officers with off-site support from forensic experts.
In this contribution as part of the Royal Society meeting on 'The paradigm shift for UK forensic science' the potential of the novel approach of integrated forensic platforms will be illustrated through current NFI innovation efforts on mobile DNA technologies (Paragraph 9.3.1), on a platform for the criminal investigation of large amounts of digital data (Paragraph 9.3.2) and on a platform allowing rapid and robust chemical identification of illicit drugs in police stations and on crime scenes (Paragraph 9.3.3).

## 9.2 The Integrated Forensic Platform, Technology to *"Connect the Laboratory to the Scene"*

In 2009 Microsoft External Research presented a vision on the future of science and introduced the fourth paradigm in science: data-intensive scientific discovery (2). From initial experimental science, to theoretical science, the introduction of computers in the last decades enabled the step to computational science. The fourth paradigm is based on the exponential availability of data to scientists through the global growth of science and the distribution of findings through world-wide networks. In the vision of Microsoft a sustainable e-infrastructure could facilitate and accelerate the generation of scientific knowledge by supporting new ways of data acquisition, modeling, sharing, visualisation, mining and archiving.
New ways of data acquisition include the use of sensors and sensor networks to gather scientific data on an unprecedented scale not only in terms of size but also in the terms of temporal and spatial resolution. Indeed in recent literature many scientific studies on wireless sensor networks have emerged reporting on sensor technology, network design, communication protocols, data aggregation and platform security (3). Sensor networks are used for so called tracking and monitoring applications. Tracking networks are employed in e.g. military, animal conservation and logistic domains while monitoring networks can have a function in e.g. health (patient monitoring) (4) and environment settings (environmental conditions, weather) (5). The nodes typically used in sensor networks still have limited measurement capability and usually determine a single or

limited set of physical or chemical parameters (e.g. temperature, pressure, oxygenation, conductivity, pH). A wireless sensor network for the on-line monitoring of water quality was recently constructed using ion selective electrodes to simultaneously measure nitrate, ammonium and chloride (5).

To be able to gather much more detailed physical, chemical and biochemical data complex devices and equipment should be connected in a network. However, this poses significant technological challenges as such measurement devices and set-ups are normally operated stand-alone in controlled laboratory conditions. Furthermore, instrument maintenance and data processing require skilled operators. A first step is made through the development of "point-of-care" devices based on regular laboratory instrumentation. Point-of-care, a term referring to health care, in this context relates to bench top equipment that do not require strict laboratory conditions and can be operated on a regular basis by trained but not necessarily skilled operators. This typically requires instrument miniaturisation, robust methodology, simplified user interfaces, automation, intrinsic calibration and quality control and integrated data processing and reporting. The final step is the deployment of fully portable, ideally hand-held devices that are connected to the sensor platform and can be used for on-site operation in real-time. The technological challenge to create portable devices with measurement capabilities similar to regular laboratory equipment is enormous. However, the reward would be equally substantial as this would result in a mobile sensor network capable of retrieving information at any desired location and time.

The current mobile smart phones offer an interesting technology platform for mobile sensors in a wireless network given the intrinsic capability to capture temporal and spatial information, transfer data and the optimised interface allowing users to perform a wide range of tasks. In recent literature the use of the mobile phone camera as spectral analyser has been reported for the chemical analysis of potassium (6) and chlorine (7), for the detection of amplified DNA (8) and for banana ripeness estimation (9). A striking example of the potential of smartphone sensor networks is the iSPEX project to monitor and map atmospheric aerosols in the Netherlands (10). Over 3000 citizen scientists participated in this study by measuring the degree of polarisation of the cloud free sky by using a special add-on for the iPhone that was provided by the research team.

The scientific insights and developments described above can be of great value to forensic science, specifically in high volume casework setting with limited forensic interpretation. There is a strong intrinsic motivation in the criminal justice system to make forensic information available as rapidly as possible as this assists in solving crime and making legal proceedings more efficient. To prevent delays that naturally occur when evidence has to be dispatched to and analysed by forensic laboratories, there is an interest in law enforcement to conduct forensic analyses in-house and directly at the scene of crime. However, the lack of controlled laboratory conditions, rigorous quality control procedures and forensic expert knowledge usually prevents findings to be used

as evidence in court. With the results being of a presumptive nature, subsequent analysis at the forensic laboratory often remains necessary. Additionally, the fragmented gathering of forensic information leads to reduced forensic oversight and insight. These problems could be tackled and the full potential of point-of-care and mobile forensic analyses could be realised when measurement devices could be operated in an integral forensic network. Through the network the necessary calibration and quality control measures could be taken that would enable deployable forensic instrumentation to yield robust findings that can directly be used as evidence. The network would allow forensic experts to assess data generated outside the forensic laboratory and to provide direct assistance to the operators on location. From these activities it also becomes apparent for which samples a more detailed follow-up investigation is required at the forensic laboratory. The forensic expert capacity is thus used more effectively and findings can be fed into the platform creating a continuous cycle of platform and data development. This approach would combine central data gathering allowing forensic intelligence and knowledge management with rapid and efficient decentralised forensic analysis. This novel concept, although technologically challenging, could lead to a step change in the efficiency and efficacy of the forensic information gathering process. It can also cause a paradigm shift in the role of forensic institutes and forensic experts in the criminal justice system. A shift towards a new role for forensic institutes and laboratories as custodians of the forensic platforms and point-of-care and portable equipment and methods. It would also allow forensic institutes to develop powerful forensic intelligence tools to reveal potential case and evidence connections, to better understand criminal activities, to monitor and optimise policing, to improve the efficiency of forensic investigations and to assist in crime prevention and disruption (11-14). The design, implementation and consequences of integrated forensic platforms will be discussed in more detail in Paragraph 9.3.

## 9.3 Integrated Forensic Platform Projects at the NFI

### 9.3.1 The Potential and Challenges of Mobile DNA Technologies

The first hours of a crime scene investigation, the so-called ‘golden hours’, are often of crucial importance for the police to get more information about the identity of potential suspects and to obtain relevant facts and data. Especially in high profile cases the criminal justice system has a strong need for immediate information to focus the investigation and formulate plausible scenarios. In the forensic setting, the time from when the crime scene sample is secured to when the results are reported in the forensic testimony is defined as the turnaround time. A recent study in the Netherlands has shown that average turnaround times (from crime scene sampling to DNA-report) are 66 days for traces from serious crimes and 44 days for traces from high volume crimes (15). This clearly illustrates that although the forensic DNA investigation chain meets all the

volume and quality requirements it does not meet the needs of the criminal justice system and specifically those of law enforcement with respect to delivery times of results.

To assist the criminal justice system in their demand for fast DNA analysis results, forensic scientists have attempted to integrate fast technologies into protocols that speed up DNA-analysis and delivers a DNA profile under stringent laboratory conditions within a short, predetermined time frame. Recently, a six hour DNA typing service has been developed and validated by the NFI (16). This has been achieved by integrating a fast PCR protocol with an inhibitor tolerant DNA polymerase. The input of DNA is regulated by the use of small lifting tapes that transfers enough but not too much DNA from a swab or fabric. By this procedure the DNA quantification step which is usually applied in routine analysis to avoid PCR artifacts by the addition of too much template DNA can be skipped.

Speed optimised methods in the forensic laboratory offer the advantage of operating in a high quality laboratory environment minimising risks of contamination and other experimental errors. Additionally, forensic DNA experts are available for the evaluation of complex profiles and criminalistic interpretation. Approved DNA profiles can quickly be added to and searched against the database. However, the disadvantage of this approach is that the samples still have to be transported to the laboratory, which takes additional time, logistic processes and paperwork. Stringent time-consuming procedures in the chain custody (from the crime scene going to the forensic facility of the police and finally to the forensic laboratory) are required to minimise the risk of sample loss, sample mix-up or incorrect labeling. The main issue remains however that the DNA analysis process should only minimally delay the progress of the criminal investigation. Ideally, forensic DNA information is provided instantly and on the crime scene location while meeting all the quality standards of the forensic laboratory.

Therefore, it is expected that in the near future, research efforts will focus on the development of technologies that will improve the speed of DNA evidence analysis. This technology will aim at robust, mobile, all-in-one platforms for STR profiling to reduce the actual turnaround time from days to hours. Currently, rapid analysis of reference material such as buccal swabs and samples containing vast amounts of DNA such as blood, is possible using the all-in-one platforms. The technical innovations in the area of fast and mobile DNA-analyses are towards creating fully integrated instruments for the analysis of DNA-traces (17). These instruments will enable the analysis of biological traces on or near the scene and connect the results directly to a reference profile from the DNA-database to identify suspects, witnesses and/or victims. With these opportunities it will be possible for an investigation team to obtain identification knowledge already at the initial stages of the crime scene investigation. Such a technological innovation will influence future criminal investigations compared to today’s standards.

When evaluating instruments for local DNA analysis it is important to be aware of the limits of performance. Although these instruments must produce the same correct and reliable DNA typing results, the mobile systems are not necessarily as sensitive as testing under laboratory conditions. The course of action of the existing mobile DNA platforms consists of integrated extraction, PCR amplification, fragment separation, and detection without human intervention. Interpretation and statistical evaluation of the results need human intervention and technical review (18). One technical mobile platform was validated by the NFI and initial results were published (19). Recent additional tests on the updated device showed great improvements with successful typing results from reference samples and crime scene stains like saliva and blood that inherently contain adequate amounts of template DNA. Future improvements such as quantification and increased sensitivity are to be expected in the near future. Due to the limited sensitivity of the available systems, an evidence based selection system of biological samples is of key importance to make a decision on whether to process the sample for rapid analysis at the crime scene or secure the sample for laboratory testing. This requires a substantial body of expert knowledge on the properties of biological traces in their potential to allow for fast mobile analysis or the necessity for processing at a fully equipped forensic DNA typing laboratory. To assist this selection process a novel "Lab-on-a-chip" technology is studied in the Netherlands (20). The aim is to develop a semi-quantitative method to screen traces at the crime scene for human DNA. The results can be provided immediately to the forensic investigation team. Pre-analysis of trace samples for human DNA may also indicate whether or not a trace is likely to be relevant for further forensic DNA analysis. Currently biological traces are frequently secured from the crime scene without any knowledge on the presence of human DNA in the trace of interest. It is expected that the future availability of a fast and sensitive DNA semi-quantification method that can be used at the crime scene will improve the selection process to obtain higher quality biological samples from the crime scene.

Despite the technological challenges that still exist, matters such as storage of DNA traces, possibility of performing a second analysis, data protection, securing privacy and a clear legal framework should also be addressed. In the Netherlands, for example, DNA profiling is only allowed upon authorisation by the Public Prosecutor, the analysis should be performed by an accredited laboratory and sufficient DNA material should be stored for additional (control/2nd opinion) analyses. The legal and quality aspects are of equal importance to create a secure, just and robust environment for the integration DNA profiling at or near the crime scene.

Regulations and procedures regarding the integration of mobile DNA platforms should also consider crime scene investigation strategies. A lack of scientific data and understanding of human factors and effective procedures at the crime scene still exists today making it challenging to fully understand the potential and pitfalls of real time DNA profiling of biological traces. Finally, the limitations with respect to complex

stains and forensic interpretation need to be carefully considered. For complex forensic DNA investigations the laboratory will stay the first choice for getting optimal typing results from mixed and low level biological traces. As these complex analyses and associated criminalistic interpretation (e.g. crime relatedness, support for prosecution and defense hypotheses) are often of crucial importance, the investigation at the scene or police station should preserve all options for advanced forensic analysis at a later stage in the DNA laboratory.

### 9.3.2 Hansken, a New Approach to Big Data Forensics

Within the NFI a new approach has been realised for processing data from various sources of digital evidence, such as data storage media from computers and mobile phones, called XIRAF (21). Since the amount of data is expanding exponentially each year, a scalable solution for processing the data is needed (22). This XIRAF approach has shown to reduce the case backlog by helping the end user understand the digital material in a timely fashion. Forensic procedures in use today place the burden of providing relevant digital evidence in the domain of the digital investigator, as well as maintaining the digital analysis and storage equipment and finally providing in-depth knowledge on the origin of the digital traces found. The implementation of an automated analysis framework shifts the task of finding relevant digital traces from the digital investigator to the tactical investigator, who has more knowledge of the facts and circumstances surrounding the case. In this way the digital investigator can put all his knowledge and education into supporting the tactical investigator with interpretation of the digital traces found as is illustrated in Figure 1. Evidence from various law enforcement agencies have shown that investigations in any urban population of roughly 15 million people generate between 4 and 20 Petabytes of data to be analysed annually, with on average 4 Terabytes of data per case. XIRAF presents all the data from a case in one overall view of the digital devices pertaining to the case. The investigator then applies queries to the data in order to reduce the set of traces. However, the XIRAF approach reached its limits at 1 Petabyte of raw data, and a more scalable successor, Hansken, was designed.

A scalable solution can only be arranged by cutting overhead costs and predominantly compute and store the data in an aggregated fashion in one (logical) place. However, it is our opinion that an aggregation on this scale can only be done when the following principles are adhered to from the earliest architecture and design phase to deployment:

- Security;
- Privacy;
- Transparency;
- Multi Tenancy;
- Future Proof;

- Data Retention;
- Reliability;
- High Availability.

Security, privacy and transparency are necessary to demonstrate to the public and magistrates that the data were handled responsibly, by whom and at what point in time. But it most of all creates a platform where analysis methods can be developed, shared and used, thus addressing the bottleneck of knowledge transfer. The rate of knowledge transfer in the digital forensics arena is not keeping up with the rate of technology change, when the methods themselves become more complicated – both to execute and to understand. By implementing the analysis in a platform it gets executed in a lot more cases with more investigators using its result. In this way also deficiencies in the analysis are found more rapidly and often, which will lead to a continuous improvement cycle.
Since the amounts of data grow very rapidly, there is a need for data reduction to remain cost effective. Several methods exist for intelligent data analysis and triage. In future approaches several methods for intelligent data analysis can be linked to Hansken. Developments in deep learning are important to use and with experience of the user queries new strategies for more efficient searches will be developed. In deep learning different representations can provide different explanations of the factors for the data. Specific domain knowledge can be used to help the design of the representations, with the possibility to use generic priors. New developments can be implemented in unsupervised feature learning and can include probabilistic models (23).

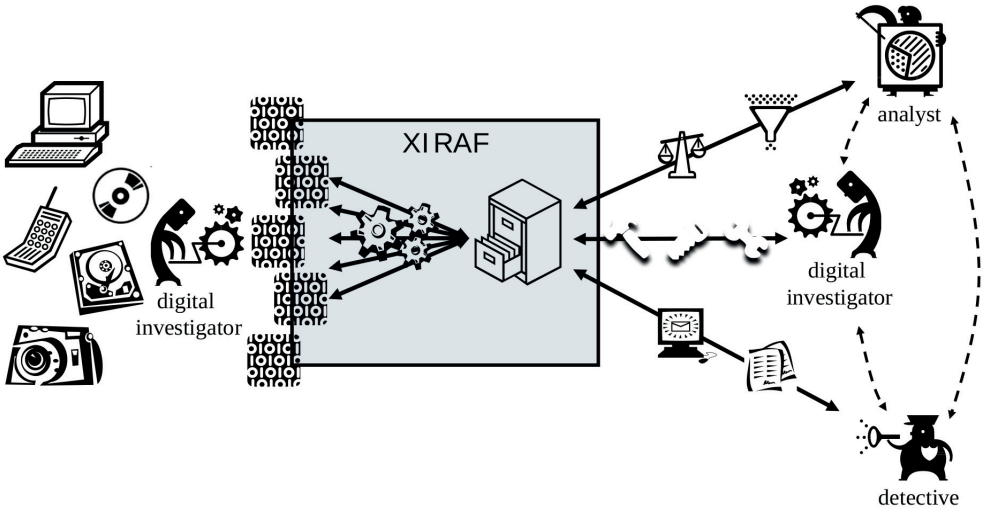



**Figure 1.** Infographic of NFI's XIRAF/HANSKEN technology illustrating the concept of a national platform for processing digital evidence in the Dutch Criminal Justice System.

Within digital data analysis it is important to provide information on the uncertainty of the digital data acquired and the conclusions that can be drawn from the data. Casey describes the different potential sources of error within digital evidence (24). These sources vary from corrupt log files to partial data that are restored from information sources as well as errors in interpretation of the data. These uncertainties are also characterised further within best practice guides on digital evidence, within the ISO 17025 framework (25). Since the ground truth in big data sets is often not known, and the determination of priors and Likelihood Ratios which are preferred within forensic science can be complex, alternative approaches such as the Big Data Bootstrap method have been suggested where an absolute confidence interval is provided instead of a relative error (26).

Images from other sources can be linked, such as databases of patterns of cameras which have been used in child pornographic cases. With the use of Camera Identification based on Photo Response Non Uniformity new links can be made with cameras (27). Also other databases such as biometric databases of faces and other body features could be linked in the future. For improving the speed of the system approaches of improving the performance with a GPU cluster are in development (28,29).

It is expected that in 2018 more than 70% of the data on the internet will be video data (30). The challenge with large amount of video and image data is however that the data are heterogenous and not standardised. For example, face recognition software is often developed for faces that are taken from frontview passport photographs. With variable views with respect to angles, distance, lighting and contrasts, it becomes more difficult to process the data automatically, although improvements are seen (31). Approaches where user interaction is necessary will help to reduce the examination time (32).

### 9.3.3 The NFiDENT Project, Reliable Drug Analysis within a Day

The problem of illicit drugs is a perpetuous and wide spread phenomenon (33). One of the tasks in the high volume process of drug analysis, is to reliably identify the nature of the seized material for court. Nowadays, the logistic and bureaucracy in the complete process of the proper identification of these illicit substances is often more time-consuming than the chemical analysis itself, making the overall endeavor suboptimal. In order to obtain useful information in an early stage of the investigation and to efficiently use the capacity of both police and forensic institutes, all kinds of presumptive testing are used (34). However, this is not a solution for the real problem at hand: the process of identifying the nature of illicit substances is inefficient and consumes too much time and thus capacity in relation to the nature of the cases.

When one might design an ideal solution for this situation:

- the processes should be simple and fast, but of such standard that immediate proof is attained. In this way, cases only have to be handled once. This will lead to an enormous reduction in paperwork and bureaucracy;
- the cases should be handled and finished/reported the same day that they are received. In this way no logistic process is needed other than transport of the sample to the final storage location (if this is not already close to the place where the illicit drugs are registered and investigated);
- the identification apparatus should be close to the place where the illicit drugs are stored;
- the technology and equipment used for identification should be robust and easy to use by non-experts and preferably based on generally accepted methodologies;
- a quality system should be designed that is safe, easy to use and capable to signal those cases where further analysis is needed, for example at a forensic laboratory with additional techniques; and
- the acquired chemical data are accessible by the forensic expert and no information is lost that is crucial/relevant for the forensic interpretation of case work.

In the Netherlands a new concept, illustrated in Figure 2, has been designed based on the ideal situation described above. This required a new way of cooperation between the National Dutch Police, Public Prosecution and the Netherlands Forensic Institute (NFI). The key elements in this new concept are:

- the placement of mobile analysis equipment at police stations;
- drug analysis measurements that are initiated by the police;
- a platform for the mobile analysis equipment that is hosted by the NFI which facilitates and integrates analysis, quality control and database management

The main objective and challenge in this new way of working is that the report for court is accepted as reliable evidence with the same status as regular forensic reports.
To identify illicit drugs in complex mixtures encountered in case work, the golden analytical standard is a combination of a separation technique and a spectroscopic technique. Typically, for the most prevalent drugs encountered on the street, gas chromatography is used in conjunction with a mass spectrometer (GC-MS) or an infrared detector (GC-IR). The traditional analysis of drug samples using a GC-MS or GC-IR system often requires time-consuming sample preparation, a chromatographic separation, and finally the (automated) recording of the MS- or IR-spectrum. Conventionally, a gas chromatograph coupled to an MS- or IR-detector is a heavy

instrument that consumes substantial watts and is a complex system that needs skilled people to operate it. To move the analysis outside the forensic lab, while still being confirmatory, it has to be simplified so that no specific analytical skills are needed. This includes sample preparation, which should be minimised as much as possible, and the whole process of identification of the targeted illicit drugs, which should be automated. A number of producers of GC-MS equipment have put effort in miniaturisation for on-site analysis of (semi-)volatiles. Transportable or hand-held systems are developed to aid homeland security at the airport, in military operations and in environmental pollution control (35-37). The developments led to commercially available analytical equipment that moved out of the forensic lab to places where less technical users need them. In case of drug samples the equipment is applied to confirm indicative results already obtained with presumptive testing used by law enforcement. When using the well-established GC-MS technique for the analysis of solid street drugs in the field without sample preparation, direct thermal desorption is a fast and reliable way of sample introduction. This type of sample introduction is made available on a number of mobile GC-MS systems under different names e.g. prepless sample introduction (PSI) probe, direct sample introduction (DSI) probe or Chromatoprobe (38). To reduce the size of the mobile GC-MS systems a transition to ion trap based mass spectrometric detectors is seen (39,40). The advantage of this type of analyser is that the pumping system does not need to maintain a very high vacuum and ions can be analysed at relatively high pressures. In addition, the possibility to implement automated tandem mass spectrometry (MS/MS) is beneficial for the identification process.

Inevitably, the transition of analytical equipment from lab-scale to a miniaturised version leads to a compromise in analytical performance. This is not necessarily an obstacle for mobile GC-MS systems as long as the forensic experts are confident with the identification process of the drugs being reported. This forces the forensic expert to validate the new GC-MS method when the transition is made from the lab to the field, i.e. the police station or scene of crime. An implication of this might be that only a limited set of illicit drugs can be identified compared to the traditional GC-MS methods. As long as this covers the larger fraction of drug samples seized, the transition still is beneficial. This also holds for the mobile FLIR G460 GC-MS system that is currently tested at the NFI and a Dutch police station. The aim of the project is that at least 80% of all illicit drugs cases can be dispatched at the police station.

When it comes to the analysis of illicit drugs a number of other analytical methods are available that might be suitable for a fast and easy identification without requiring sample preparation. These methods are either based on mass spectrometry only, through direct ionisation of substances from (solid) drug samples followed by MS(n) (41), or are based on spectroscopic techniques like (near) infrared (42) or RAMAN-spectroscopy (43,44). The use of spectroscopic techniques is underestimated in many forensic

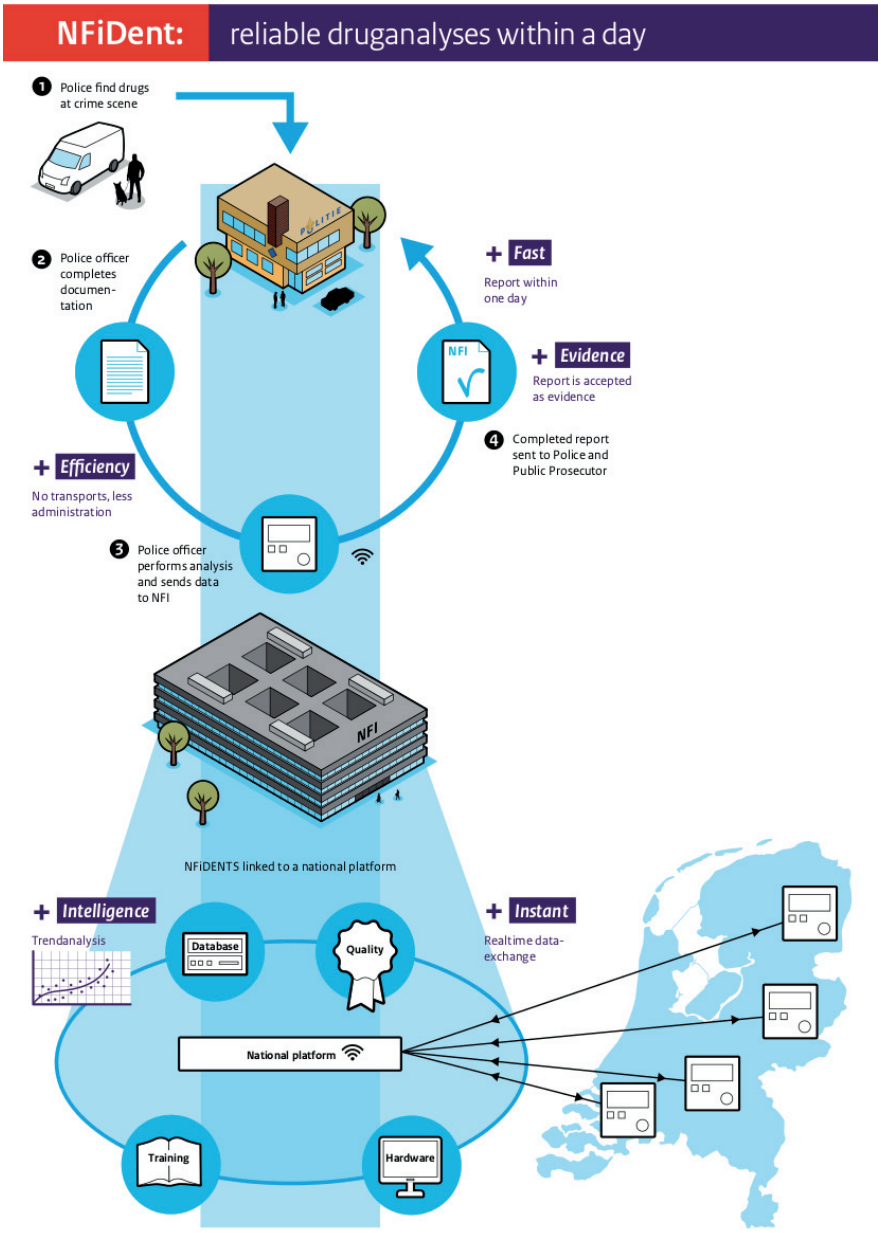



**Figure 2.** Infographic of the NFIdent project illustrating the concept of a national platform for accredited drug analysis and identification in the Dutch Criminal Justice System.

laboratories largely because of the difficulty to get robust results when illicit drugs are mixed with rare cutting agents or contain unusual and unknown excipients.
However, the capabilities of modern spectroscopic equipment have improved, including direct sampling devices to minimise sample preparation and multi component algorithms to identify illicit drugs in typical street samples (45). The two main advantages of a spectroscopic analysis are the analysis time and the costs involved. A drawback of these techniques used to be the relatively high limits of detection compared to traditional GC-MS methods used for the most prevalent drugs but improvements in chemometrics have pushed the boundaries to lower levels. Unfortunately, in contrast to GC-MS analysis, a thorough investigation/validation of the discriminative power of these methodologies never has been reported/published for illicit drugs like cocaine or amphetamine type stimulants, and it is unknown whether all possible stereoisomers and/or homologs can be distinguished from these substances with these spectroscopic techniques. Depending on the spectroscopic technique and the composition of the drug sample the spectra obtained are not always interpretable and it all comes down to the ability of the software used for chemometric analysis to identify illicit drugs present and the way results are displayed for court presentation.
The use of direct ionisation techniques, also known as ambient ionisation techniques, for the mass spectrometric analysis of illicit drugs with limited or without sample preparation is a proven analytical
method for easy and fast on-site identification. A large number of ambient ionisation methods has been developed, with desorption electrospray ionisation (DESI) (46) and direct analysis in real time (DART) (47) being the most familiar modes. When first introduced, these ionisation techniques were directly coupled to expensive, sophisticated commercial mass spectrometers which require skilled operators and laboratory condition. Nowadays, a number of miniaturised MS systems has been developed based on different types of ion trap mass spectrometers which use an ambient ionisation source for direct analysis (48).
Two promising ambient ionisation techniques that can be easily installed and operated in combination with miniaturised MS systems are low temperature plasma (LTP) desorption and paper spray ionisation. LTP desorption is based on active species that are formed in a low power plasma. This gentle desorption/ionisation technique has the advantage that the surface is hardly modified when chemicals are sampled directly from the surface of the illicit drug containing material (49). With paper-spray ionisation ions are generated, comparable to (nano-) electrospray desorption, directly from a sample that has been place on a triangular shaped paper substrate by applying a high voltage to the paper while adding a small amount of solvent(s) (48,50). The application of the drug sample to the paper can be done by wiping or by the application of a solution to the paper.

In the case of complex mixtures a lot of different substances can be desorped, ionised and introduced into the ion trap. For further identification an automated MS-MS analysis (Multiple Reaction Monitoring) should be performed on selected drug analytes expected to be present based on the results of the presumptive tests. In addition, the presence of a combination of m/z values in the overall MS spectrum that can be ascribed to known by-products or regular cutting agents of the targeted drugs might assist the identification process.
The current trend in analytical instrumentation development is high performance, smaller instrumentation with sophisticated software, and a simplified user interface. Ideally, the function and capability of these modern devices should be tailored to the drugs substances that need to be identified. For the analysis of solid drugs samples it is anticipated that the development of a robust and easy operable small mass spectrometer in connection with direct ionisation capability, adequate MS analysis performance and fit –for purpose software will eliminate the requirement for complex, time consuming sample pretreatment and chromatographic separation.

## 9.4 Concluding Remarks on the Future of Forensic Science

Further advancements in forensic science in combination with the introduction of new technology and methods that create an added value (innovation) for the end user will definitely be able to cause a paradigm shift within the criminal justice system. However, according to Downes' Law of Disruption, technology changes exponentially while social, economic and legal systems change incrementally (51). This makes it difficult for new technology to be introduced and implemented. Although Downes' Law points at the fast developments in the digital world, it also holds for many other areas and especially for the criminal justice system as new legislation and extensive quality control measures are required to allow for new forensic methodology to be regularly applied.
The application of new science and technology during the past decades, e.g. in the areas of microbiology, chemistry and information technology, have already created a considerable growth in demand of forensic science services. If new technology is available that can provide valuable information to solve crime, there will immediately be a strong demand for it.
It is important to realise that within the context of the scientific areas mentioned above new classes of trace evidence came into play. These classes were simply not taken into consideration previously, either because the evidence did not exist before and/or no methods were available to investigate the evidence. This is definitely the case for digital forensic science that has created a completely new world of trace classes. Nowadays people live in a hybrid world in which they leave both physical and digital traces. In the Netherlands in the 21st century there is hardly any criminal investigation in which

digital traces do not play a role. It is, therefore, crucial for forensic service suppliers to be able to retrieve and analyse traces from all available digital sources.
Another reason for the growth in the demand of forensic services is the awareness of the end-users of what forensic science has to offer. This has also created a more demanding end-user, that is able to formulate its innovative needs (52). The latter is extremely important to be able to determine those areas in which R&D and innovation are necessary. These efforts should be focused on providing investigators and legal experts with more timely and relevant information.
The success of forensic science over the past decades has come at a price. Due to the organisational structure of the sector and the forensic institutes within it, the growth in demand resulted in many instances in severe backlogs and consequently long turn-around times. The resulting pressure on the operational side of the organisations has created a barricade for continued innovation and is thus delaying the expected paradigm shift. The basic problem is that most forensic science institutes are typically budget oriented organisations with limited resources that cannot grow rapidly and significantly enough to keep up with the increase in demand.
Although it is tempting to try and find ways to increase capacity, the backlog problem has to be tackled from a much more fundamental perspective based on the role and efficacy of the overall criminal justice system. At the NFI these insights have resulted in innovation efforts aimed at integrating forensic science and state-of-the-art technology to initiate the construction of forensic platforms allowing a much more efficient investigation of evidence. It takes courage to work on technology that aims for forensic investigations to be conducted outside the laboratory by non-experts. Can the required robustness and quality be guaranteed and will successful implementation in the end result in the reduction of the expertise and capacity at the forensic institutes? However, our experiences in the innovation projects described in this paper have so far been very positive. These projects have fuelled enthusiasm and strong support and participation from our key partners. Additionally, the forensic experts have started to discover the possibilities to increase the added value from the advanced methods at the laboratory. By providing robust field solutions for standard conditions, the integrated forensic platform will not only allow for more expert capacity for complex cases it will also signal the cases where such additional investigation is needed. This ultimately leads to a much more efficient use of relatively scarce skills and knowledge by replacing a large volume of standard cases by a lower volume of complex cases.
Clearly one of the most important requirements to design, develop and implement fully integrated forensic platforms is sufficient financial resources to perform the necessary R&D and quality studies. Fortunately, national research funding organisations (e.g. science foundations) start to become more aware of the opportunities forensic science can offer. This is also true for the European Union. Research funds from DG Home Affairs and -last but not least- the Horizon 2020 funds from DG Research offer relatively

large funding opportunities for forensic science related research. Additionally there is a need to continuously implement the latest technology in these platforms. Such technology is often created outside the forensic domain and needs to be made "fit for forensic purpose" including forensic scientific validation. This requires an interdisciplinary "triple helix" approach in which academic institutes, innovative companies and forensic experts collaborate. Ideally, such collaborations are of an international nature and yield solutions that can be used by a multitude of countries. A more international oriented structure would definitely help to create more innovation potential despite the strong national nature of judicial systems. The current initiatives within the European Union to create a European Forensic Science Area (EFSA 2020) and within the USA to create a Forensic Science Center of Excellence will hopefully fuel a more open and less fragmented structure in which integrated and international forensic solutions such as integrated platforms can emerge.

## 9.5 References


1. Asten van AC. On the added value of forensic science and grand innovation challenges for the forensic community. *Science & justice,* 2014;54(2):170-179
2. Tolle KM, Tansley DSW, Hey AJG (eds). 2009. *The fourth paradigm: data-intensive scientific discovery.* Microsoft Corporation. Retrieved from: http://research.microsoft.com/en-us/collaboration/fourthparadigm/4th_paradigm_book_complete_lr.pdf.
3. Yick J, Mukherjee B, Ghosal D. Wireless sensor network survey. *Computer Networks,* 2008;52(12):2292-2330.
4. Alemdar H, Ersoy C. Wireless sensor networks for healthcare: a survey. *Computer Networks,* 2010;54(15):2688-2710.
5. Capella JV, Bonastre A, Ors R, Peris M. A wireless sensor network approach for distributed in-line chemical analysis of water. *Talanta* 2010:80(5);1789-1798.
6. Garcia A, Erenas MM, Marinetto ED, Abad CA, de Orbe-Paya I, Palma AJ, Capitan-Vallvey LF. Mobile phone platform as portable chemical analyzer. *Sensors and Actuators B: Chemical*, 2011;156(1):350-359.
7. Sumriddetchkajorn S, Chaitavon K, Intaravanne Y. 2013 Mobile device-based self-referencing colorimeter for monitoring chlorine concentration in water *Sensors and Actuators B: Chemical* 2013;182:592-597.
8. Lee D, Chou WP, Yeh SH, Chen PJ, Chen PH. DNA detection using commercial mobile phones. *Biosensors and Bioelectronics,* 2011;26(11):4349-4354.
9. Intaravanne Y, Sumriddetchkajorn S, Nukeaw J. Cell phone-based two-dimensional spectral analysis for banana ripeness. *Sensors and Actuators B*, 2012;168:390-394.
10. Snik F et al. Mapping atmospheric aerosols with a citizen science network of smartphone spectropolarimeters. *Geophysical Research Letters*, 2014;41(20):7351-7358.
11, Bell C. Concepts and possibilities in forensic intelligence. *Forensic Science International*, 2006;162(1):38-43.
12. Ribaux O, Baylon A, Roux C, Delemont O, Lock E, Zingg C, Margot P. Intelligence-led crime scene processing. Part I: forensic intelligence. *Forensic Science International*, 2010;195(1-3):10-16.
13. Morelato M, Baechler S, Ribaux O, Beavis A, Tahtouh M, Kirkbride P, Roux C, Margot P. Forensic intelligence framework—Part I: introduction of a transversal model by comparing illicit drugs and false identity documents monitoring. *Forensic Science International*, 2014;236:181-190.
14. Ross A. 2015 Elements of a forensic intelligence model. *Australian Journal of Forensic Science,* 2015;47(1):8-15.
15. Mapes AA, Kloosterman AD, & Poot de CJ. DNA in the criminal justice system: the DNA success story in perspective. *Journal of forensic sciences*, 2014;*60*(4):851-856.
16. Verheij S, Harteveld J, Sijen T. A protocol for direct and rapid multiplex PCR amplification on forensically relevant samples. *Forensic Science International: Genetics,* 2012;6(2):167-175.
17. Vallone PM. Rapid DNA testing at NIST. 2014. Retrieved from:

http://www.cstl.nist.gov/strbase/pub_pres/ Vallone_GIS_Sept_2014.pdf.
18. Information on rapid DNA profiling provided by the Federal Bureau of Investigation on the FBI website. 2014. Retrieved from: http://www.fbi.gov/about-us/lab/ biometric-analysis/codis/rapid-dna-analysis.
19. Verheij S, Clarisse L, van den Berge M, Sijen T. RapidHIT™ 200, a promising system for rapid DNA analysis. *Forensic Science International: Genetics,* 2013;4(1):e254-e255.
20. Bruijns BB, Kloosterman AD, de Bruin KG, van Asten AC, Gardeniers JGE. 2012 Presumptive human biological trace test for crime scenes, based on lab- on-a-chip technology—'HuBiTT'. In Poster presented at the EAFS 2012 Conference, The Hague, The Netherlands, 20 – 24 August, 2012. ENFSI and NFI.
21. Baar van RB, Beek van HMA, Eijk van EJ. Digital forensics as a service: a game changer. *Digitital Investigation,* 2014;11:54-62.
22. Quick D, Choo K-KR. Impacts of increasing volume of digital forensic data. *Digitital Investigation,* 2014;11;273-294.
23. Bengio Y, Courville A, Vincent P. Representation learning: a review and new perspectives. *IEEE Transactions on Pattern Analalysis and Machine Intelligence,* 2013;35(8):1798-1828.
24. Casey E. Error, uncertainty, and loss in digital evidence. *International Journal of Digital Evidence,* 2002;1(2):1-45.
25. ENFSI. Guidelines for best practice in the forensic examination of digital technology. ENFSI Best Practice Guide, v. 6. 2009. Retrieved from: http://www.enfsi.eu/ sites/default/files/documents/ forensic_it_best_practice_guide_v6_0.pdf.
26. Kleiner A, Talwalkar A, Sarkar P, Jordan M. The big data bootstrap. In Proc. 29th Int. Conf. on Machine Learning, Edinburgh, UK, 26 June – 1 July 2012. ICML 2012 Handbook, p.112.
27. Gisolf F, Malgoezar A, Baar T, Geradts Z. Improving source camera identification using a simplified total variation based noise removal algorithm. *Digitital Investigation,* 2013;10(3): 207-214.
28. Werkhoven van B, Maassen J, Bal HE, Seinstra FJ. Optimising convolution operations on GPUs using adaptive tiling. *Future Generation Computer System*, 2014;30:14-26.
29. Daniel G, Neeb M, Gipp M, Kugel A, Männer R. Correlation analysis on GPU systems using NVIDIA's CUDA. *Journal of Real-Time Image Processing,* 2011;6(4):275280.
30. Cisco company. The Zettabyte era. White Paper. 2014. Retrieved from: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/VNI_Hyperconnectivity_ WP.pdf.
31. NIST. Face recognition vendor test, NIST report, 2013. Retrieved from: http://biometrics.nist.gov/cs_links/ face/frvt/frvt2013/NIST_8009.pdf.
32. Rooij de O, Worring M. Efficient targeted search using a focus and context video browser. *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)*, 2012;8(4);51.
33. Executive Office of the President of the USA, Office of National Drug Control Policy. 2011 How illicit drug use affects business and the economy. Retrieved from: http://www.whitehouse.gov/sites/default/files/ondcp/Fact_Sheets/ effects_of_drugs_on_economy_jw_5-24-11_0.pdf.
34. Tsumura Y, Mitome T, Kimoto S. False positives and false negatives with a cocaine-specific field test and modification of test protocol to reduce false decision. *Forensic Science International,* 2005;155(2):158-164.
35. Eckenrode BA. Environmental and forensic applications of field-portable GC – MS: an overview. *Journal of the American Society for Mass Spectrometry*, 2001;12(6):683-693.
36. Smith PA, Jackson Lepage CR, Koch D, Wyatt HDM, Hook GL, Betsinger G, Erickson RP, Eckenrode BA. Direct detection of gas-phase chemical warfare agents using field-portable gas chromatography-mass spectrometry systems: instrument and sampling strategy considerations. TrAC Trends in Analytical Chemistry, 2004;23(4):296-306.
37. Sekiguchi H, Matsushita K, Yamashiro S, Sano Y, Seto Y, Okuda T, Sato A. On-site determination of nerve and mustard gases using a field-portable gas chromatograph-mass spectrometer. *Forensic Toxicology,* 2006;24(1):1722.
38. Wainhaus SB, Tzanani N, Dagan S, Miller ML, Amirav A. Fast analysis of drugs in a single hair. *Journal of the American Society for Mass Spectrometry*, 1998;9(12):1311-1320.
39. Contreras JA, Murray JA, Tolley SE, Oliphant JL, Tolley HD, Lammert SA, Lee ED, Later DW, Lee M. Hand-portable gas chromatograph-toroidal ion trap mass spectrometer (GC-TMS) for detection of hazardous compounds. *Journal of the American Society for Mass Spectrometry,* 2008;19(10):1425-1434.
40. Gao L, Song Q, Patterson GE, Cooks RG, Ouyang Z. Handheld rectilinear ion trap mass spectrometer. *Analytical Chemistry*, 2006;78(17); 5994-6002.
41. Wells JM, Roth MJ, Keil AD, Grossenbacher JW, Justes DR, Patterson GE, Barket Jr DJ. Implementation of DART and DESI ionisation on a fieldable mass spectrometer. *Journal of the American Society for Mass Spectrometry,* 2008;19(10):1419-1424.

42. Moros J, Galipienso N, Vilches R, Garrigues S, de la Guardia M. Nondestructive direct determination of heroin in seized illicit street drugs by diffuse reflectance near-infrared spectroscopy. *Analytical Chemistry,* 2008:80(19);7257-7265.
43. Vitek P, Ali EMA, Edwards HGM, Jehlicka J, Cox R, Page K. Evaluation of portable Raman spectrometer with 1065 nm excitation for geological and forensic applications. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 2012;86:320-327.
44. Hargreaves MD, Page K, Munshi T, Tomsett R, Lynch G, Edwards HGM. Analysis of seized drugs using portable Raman spectroscopy in an airport environment—a proof of principle study. *Journal of Raman Spectroscopy,* 2008;39(7):873-880.
45. Katainen E, Elomaa M, Laakkonen UM, Sippola E, Niemela ̈P, Suhonen J, Järvinen K. Quantification of the amphetamine content in seized street samples by Raman spectroscopy. *Journal of Forensic Sciences,* 2007;52(1):88-92.
46. Cooks RG, Ouyang Z, Takats Z, Wiseman JM. Ambient mass spectrometry. *Science,* 2006:311(5767):1566-1570.
47. Cody RB, Larame ́e JA, Durst HD. Versatile new ion source for the analysis of materials in open air under ambient conditions. *Analytical Chemistry,* 2005:77(8);2297-2302.
48. Li L, Chen T-C, Ren Y, Hendricks PI, Cooks RG, Ouyang Z. Mini 12, miniature mass spectrometer for clinical and other applications— introduction and characterization. *Analytical Chemistry,* 2014;86(6):2909-2916.
49 Harper JD, Charipar NA, Mulligan CC, Zhang X, Graham Cooks R, Ouyang Z. Low-temperature plasma probe for ambient desorption ionisation. *Analytical Chemistry,* 2008;80(23):9097-9104.
50. Wang H, Liu J, Cooks RG, Ouyang Z. Paper spray for direct analysis of complex mixtures using mass spectrometry. *Angewandte Chemie*, 2010;122(5):889892.
51. Downes L. *The laws of disruption*. New York, NY;Basic Books: 2009
52 Harnessing science and innovation for forensic investigation in policing. Vision document from Association of Chief Police Officers. 2012. Retrieved from: https:// connect.innovateuk.org/web/forensics/article- view/-/blogs/harnessing-science-and-innovation-for-forensic-investigation-in-policing.


R-DNA

# Chapter 10

## Reflection and Future Perspective

## 10.1 Introduction

The work in this thesis shows that mobile Rapid DNA technologies are a promising effective tool for forensic intelligence purposes to identify a suspect. It also became clear that for an optimal implementation technological, behavioural and legal implications must be taken into account for Rapid DNA analysis to become a CSI reality. Before Rapid DNA can be implemented in criminal investigations, serving both intelligence and evidence purposes, the studies in this thesis investigated the importance of the DNA prioritisation and selection process, the impact of human factors and the juridical process. To make the most of the potential of Rapid DNA the last chapter from this thesis provides the Criminal Justice System (CJS) with a summary and discussion on the findings leading to a final evidence-based road map showing the practical and scientific value of the studies performed. The thesis concludes with a future perspective on the way forward in speeding up forensic DNA analysis.

## 10.2 Summary of Key Findings

Rapid DNA Technologies at the Crime Scene - 'CSI' Fiction Matching Reality

This thesis investigated the impact of implementing mobile Rapid DNA technologies at the crime scene to identify a perpetrator, and to optimally regulate the process of analysing and obtaining Rapid DNA profiling results to ensure acceptance within the criminal justice system.

*DNA as an investigative tool*

In the first study of this thesis (Chapter 2**)**, it is shown that in 1% of the forensically investigated high volume crime cases a 'cold hit' was obtained through DNA analysis and database searching.

In serious crime cases, an unknown suspect was identified through the DNA evidence in 3% of the cases. The study also revealed that 17% of the analysed High Volume Crime (HVC) traces, and 38% of the analysed Serious Crime (SC) traces did not provide DNA typing results. In addition, the analysis shows relatively long turnaround times from crime scene to DNA result and forensic testimony. In a number of cases, a suspect was identified through other investigative methods before the DNA match was reported. In these situations, DNA loses its intelligence potential, but can possibly still serve as evidence in court.

It can be expected that in cases with enough DNA, Rapid DNA analysis can be used as an investigative tool to speed up the identification of unknown suspects. Rapidly identifying suspects could lead to a discontinuation of other investigations, such as

witness hearing, analysing telecommunication data, or viewing footage from surveillance cameras.

*Technological implications – DNA success rates*

Rapid DNA analysis is less sensitive than laboratory analysis. This must be taken into account for future Rapid DNA analysis decisions, and implies that DNA success rates are of key importance. To define DNA success rates, the second study (Chapter 3) focuses on the DNA concentrations of a large variety of crime related samples, to predict DNA profiling results and select promising samples for DNA analysis. Saliva and contact traces from intensively used items, such as collars and headwear, show high DNA concentrations potentially leading to full profiles. The proximity, intensity, and duration of the contact are factors that seem to contribute to the profiling success. This study further indicates that from each category of traces a certain amount is expected to lead to informative profiles. These success rate data can assist the DNA prioritisation process. Although this gives an insight into the DNA concentrations of various categories of traces, it shows no actual DNA success rates.

Actual data on DNA success rates are given in the follow-up and third study of this thesis (Chapter 4)**,** where 28 different categories of trace exhibits were analysed. The study focuses on profile characteristics, including: the DNA concentration, the type of profile, and the matches that were obtained. Half of the samples contained too little DNA to obtain DNA typing data. A positive relation between the success probability and the DNA concentration was observed, and appears to be independent of the type of crime sample. Setting a DNA concentration 'cut-off' could, therefore, optimise the DNA analysis procedure at the laboratory to focus on analysing more promising crime samples. It is expected that this protocol will lead to a more effective procedure reducing the number of 'empty' traces.

In more detail, the study shows that samples from cigarette ends, bloodstains, and headwear had relatively high success rates; whereas, cartridge cases, tools, tape, and zip ties were on the other end of the spectrum. This leads to a trace specific detailed model on DNA success rates to assist SoCOs in prioritising and selecting DNA traces. In this model we have defined our four-step decision process: 1) collect evidentiary traces, 2) rank traces based on crime and/or offender relatedness, 3) use the DNA success rate figure to rank the highest crime and/or perpetrator related traces and 4) select the most promising traces for DNA analysis. We expect that this knowledge will make SoCOs more aware of what to sample at the crime scene, and which samples to analyse with Rapid DNA or forward for laboratory analysis.

*Technological implications – Rapid DNA and our DNA success rate model*

The fourth study (Chapter 5**)** aimed to use the DNA success rate knowledge to support the selection process of crime samples for analysis by Rapid DNA. The study showed

that less sensitive technologies will have a significant impact on the DNA success rates. Without careful consideration, this could lead to loss of potentially valuable crime scene DNA samples. Samples with a low quantity of DNA seem less appropriate for analysis with a Rapid DNA device. Crime samples that show a high success rate in the laboratory will therefore also have the highest potential for Rapid DNA.
Although Rapid DNA cannot compete with the full potential that the laboratory offers, it can lead to important intelligence within hours. To make optimal decisions for DNA trace analysis, knowledge on Rapid DNA success rates is of crucial importance. For this purpose, an easy to use model was designed that can deal with any sensitivity threshold. This model showed both the laboratory, and potential Rapid DNA success rates, depending on the sensitivity threshold. Exact sensitivity thresholds of the Rapid DNA technology are still unknown and need to be derived from future validation studies. For instance, when a Rapid DNA device has a sensitivity level of 25 pg/μL DNA, the model shows that a DNA profile would be derived from a balaclava sample in 85% of the cases, whereas the laboratory would produce a profile from a balaclava sample in 92% of the cases. This shows a false negative value of 7% when analysing a balaclava sample with the Rapid DNA device.
This information can be incorporated in our four-step decision process and used by the SoCOs to decide whether to analyse a trace rapidly at the crime scene or forward the sample to the laboratory.

*Behavioural implications*
The perception of the technological implications for Rapid DNA analysis is expected to be crucial for future crime scene practice, and the decision-making process. For this purpose, the fifth study (Chapter 6**)** outlines a 'real-life' experiment to test the behavioural implications. SoCOs all performed the same mock crime scene investigation of a violent home robbery, either with or without the opportunity for Rapid DNA analysis. This study implies that a criminal case can be solved more quickly with Rapid DNA. However, with Rapid DNA at hand, significantly more DNA traces were selected for analysis. These traces were often victim related, of which most were not even crime related. More importantly, the traces analysed with Rapid DNA analysis were often either contact or interdisciplinary traces. SoCOs appeared to lack adequate knowledge on DNA success rates, risking the loss of informative low template DNA traces through rapid analysis. On top of that, DNA success rates were rarely considered when making decisions for trace DNA analysis. The study reveals the need for a comprehensive framework to support the DNA decision process.
These behavioural implications clearly indicate that current crime scene procedures need adjusting, and could benefit from a more transparent decision process in which opportunities and risks are explicitly considered when Rapid DNA analysis will be implemented. The previously explained four-step decision process could be extended to

a 'hierarchy of decisions' for Rapid DNA analysis:

1) Detect and collect all evidentiary traces;
2) Rank the traces by crime relatedness;
3) Rank the presumed crime related traces by perpetrator relatedness;
4) Use the Rapid DNA success rate figure for further selection;
5) Select the most promising trace(s) for Rapid DNA analysis;
6) Reconsider all collected traces in the light of different crime scenarios with the investigative team after the crime scene investigation;
7) Decide for further DNA analysis.

The reconsideration step forces the SoCOs to evaluate their CSI, the analysis decisions, and subsequent steps. Especially when Rapid DNA analysis will lead to identifying a suspect, it is of importance to reconsider all other traces that could identify the offender(s) or give insight into how the crime was committed. This might not rule out potential error or biased decisions, but it could assist in a more transparent and thoughtful decision-making process.

*Legal implications*

It is expected that identifying information obtained in the intelligence phase of the investigation will also play a crucial role in the evidence phase when the case goes to court. However, the sixth study (Chapter 7) shows that the Dutch law states that only an appointed DNA expert working for an accredited laboratory is entitled to provide the DNA evidence.

So, although a SoCO could perform Rapid DNA analysis where the results are used for intelligence purposes, the results cannot be used in the evidence phase when the case goes to court. It should be taken into account that the law on forensic DNA analysis dates from 1994 when DNA analysis was labour intensive and time consuming. In the past two decades DNA analysis opportunities have grown exponentially. These developments can even lead to amendments of the DNA law, for instance as happened in 2012, when familial searching and eye colour analysis for forensic purposes became effective (1). This shows that amending the law can be a solution to regulate the use of Rapid DNA analysis at the crime scene. The study outlined in Chapter 6 shows that in this process the following safeguards should be considered: 1) the public prosecutor is the requesting authority, 2) the implementation of a protocol detailing the specifications that the device must comply with, 3) implementation of a protocol to regulate the DNA traces to be analysed, 4) SoCOs receive additional training in the Rapid DNA procedure, 5) additional analysis and contra-expertise must remain possible, and 6) the situation at the crime scene and the subsequent process must be recorded meticulously.

*Decision Support System*

The technological implications show that Rapid DNA analysis can result in false negative profiling results; whereas, the behavioural implications show that SoCOs have the desire to analyse crime samples (including low template DNA samples) rapidly. In addition, the legal implications require SoCOs to use protocols to support the knowledge-based decision process. For this purpose, the seventh study (Chapter 8**)** focused on designing and testing a DSS, to combine these implications, and to guide SoCOs in making Rapid DNA analysis decisions.

With a Rapid DNA opportunity at hand, the SoCO needs to decide whether to analyse a crime sample with a less sensitive Rapid DNA device to get results within 2 hours, or to secure and have the sample analysed at the laboratory with a much longer throughput time but with higher sensitivity. To make an optimal decision it is important to systematically define this 'time/success rate trade off' in some sort of numerical threshold that can be compared with the Rapid DNA success rates. Through a specifically designed DSS, SoCOs are forced to consider all the possible outcomes through assigning numerical weights that, based on Rational Decision Theory, will lead to a Rapid DNA analysis threshold for the specific case. This threshold can be combined with the Rapid DNA success rates to support their final decision on using the Rapid DNA technology. In this way, both opportunities and risks are made explicit before a decision is reached.

This model was tested in a vignette study, where SoCOs had to decide on the use of a Rapid DNA analysis device, either with or without guidance through a DSS. In this study, the participants received constrained case characteristics, and were forced towards considering only one perpetrator related trace in their decision to use Rapid DNA analysis. It should be realised that in real cases there are more characteristics that could be implemented in the DSS, such as possible additional perpetrator related traces, and the expected relevance of the traces.

The study showed that setting thresholds with the DSS is a difficult matter. More than half of the participants using a DSS made Rapid DNA decisions that did not correspond to their chosen threshold. However, the qualitative data suggested that these participants rationally decided against their chosen threshold, potentially because they learned the effect of the threshold when applying it in a concrete case. The future challenge is therefore to agree upon the best-fitting uniform thresholds for several cases, and create easy to use expert systems for this purpose. This study further shows that SoCOs made different, but more justifiable, decisions for Rapid DNA analysis when guided by a DSS. The decision to apply Rapid DNA analysis or not was significantly influenced by the factors 'time-pressure', and 'trace characteristics' like DNA success rates. This indicates that future crime scene practice could benefit from such a DSS, especially when this would be combined with the 'hierarchy of decisions'. It is expected that such a decision model will minimise both human errors such as confirmation, commitment, or mood

bias, and technological errors such as false negative profiling results through the rapid but less sensitive analysis, and will ultimately encourage the optimal use of a Rapid DNA analysis device at the crime scene.

*The future of Rapid DNA at the crime scene*

The eighth and last study from this thesis (Chapter 9), concludes that the CJS has a strong intrinsic motivation to gain rapid forensic analysis results to assist vastly identifying of suspects, solving crimes and making legal proceedings more efficient. Due to the technological possibilities and improvements of Rapid DNA, the role of forensic institutes is expected to change. This change of speeding up analysis at the crime scene is aimed at providing a robust field solution for routine practices. The future perspective is to create integrated forensic platforms, where forensic expert knowledge and police practice are integrated. Together with carefully considered legislation, extensive quality control measures and a thought-out decision model, the state-of-the-art Rapid DNA technology will have clear value for the CJS.

## 10.3 Making Rapid DNA Safe for Practice

This thesis extrapolated and combined the technological, behavioural, and legal implications to study how Rapid DNA technologies may be integrated in crime scene practice. This study delivered knowledge on the juridical process, DNA success rates, and human behaviour on the decision process for rapid trace DNA analysis. In this study we focused on the use of Rapid DNA for perpetrator identification purposes, and not for reconstruction or evidence purposes; neither did we analyse the impact of other traces, such as fingerprint traces, that could also lead to identification and therefore may influence the decision to use the Rapid DNA device.

Designing effective new strategies and guidelines for the integration of the Rapid DNA technology requires an understanding of the complete field of crime scene practice (2). This thesis serves as an important foundation for this purpose. However, the use of Rapid DNA will affect the entire criminal investigation process and all professionals involved. The speed of the analysis process requires real-time information flow between the parties involved in the criminal investigation; in particular, the investigative officers who have to act on the rapid identification information. It is essential to establish an optimal connection between forensic and investigative officers to further optimise the Rapid DNA analysis procedure. Rapid DNA results can lead to faster identification of a perpetrator but can also lead to an early onset of tunnel vision. These effects and side effects of Rapid DNA information were not taken into consideration in this thesis, but are a central theme in a parallel thesis (3).

Although the full picture on integrating Rapid DNA at the crime scene might not yet be complete, the Dutch police are dedicated to start the use of Rapid DNA technology in

their crime scene investigation. The results obtained so far enabled us to design a conceptual Rapid DNA decision-model and CSI procedure to facilitate this process. These concepts can be used as a prototype for guiding future Rapid DNA analysis decisions at the crime scene, and are outlined in the next two paragraphs. It is important to realise that the current knowledge for these processes will be kept up to date, and new information will be gathered to further optimise the decision-model. Additional knowledge will make the Rapid DNA decision-model, and CSI procedure more advanced.

The goal of this model and procedure is not only to minimise potential human bias and decision errors while keeping the focus on the crime scene investigation, but also to maintain the chain of custody at all times. Therefore, all steps need to be directed and easy to log. Implementation of Rapid DNA technologies at the crime scene entails testing this Rapid DNA procedure and decision-model within actual cases in an experimentally designed pilot. The first steps towards this pilot have been set out and confirm that Rapid DNA analysis may be a viable alternative in the future (4).

### 10.3.1 CSI Procedure

When integrating mobile Rapid DNA analysis technologies at the crime scene, the standard 4-phase model for CSI needs modification to allow for Rapid DNA analysis. Currently, in a criminal investigation the trace detection, prioritisation and selection, the analysis, and the final interpretation are all separate procedures. The Rapid DNA opportunity will lead to the integration of all these steps directly at the crime scene. Therefore, it is recommended to adjust and extend the 4-phase model for CSI to an adaptive CSI procedure as follows:

1. The first step in this CSI procedure does not change, and consists of an orientation and potential detection of the first visible (DNA) traces.
2. The second step is to create the plan of approach and to define the initial scenarios. In this stage, the use of Rapid DNA could be immediately considered. This either leads to continuing the standard procedure or following the Rapid DNA procedure (through using a decision-model, see next paragraph). After collecting the specific traces and using Rapid DNA analysis, the results could lead to new information which may result in revising the plan of approach. The continuous reassessment of the plan of approach is a fundamental new element in the proposed CSI procedure.
3. The third step is to proceed with the CSI, and detect, collect and document all the localised physical evidence on the crime scene. This step could again be a reason to decide to use Rapid DNA and reassess the plan of approach.
4. When the third step is completed, the SoCOs perform a final walk through and round up of the CSI (step 4).

5. After rounding up the practical CSI, the fifth step is used to reconsider all collected traces and gathered information to define final scenarios with the investigative team, forensic analysts, and experts.
6. With the knowledge obtained, traces will be prioritised and potentially selected for further rapid or laboratory analysis. This step could again be a reason to decide to use Rapid DNA and reassess the plan of approach.

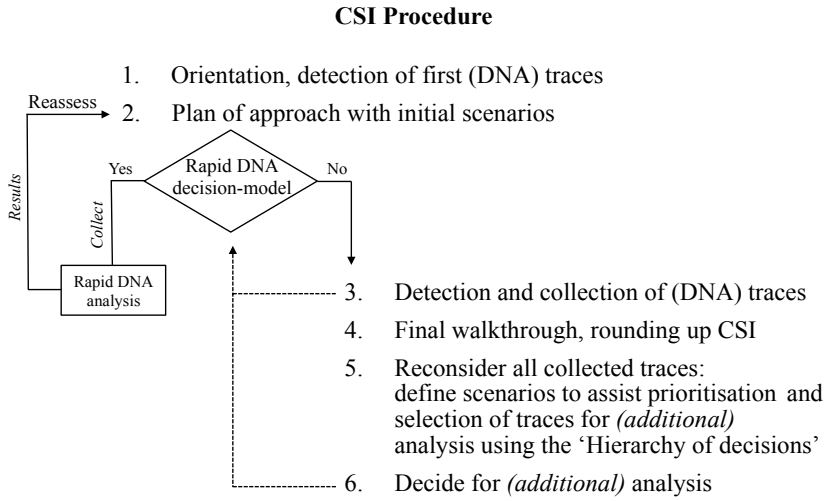



**Figure 1.** Renewed CSI Procedure for Trace (DNA) Analysis

When Rapid DNA analysis provides identification results, this potentially leads to immediate forensic intelligence that could require direct sharing with the investigative team. In that instance, it is crucial for SoCOs to realise the CSI practice is still on-going, and that it is therefore essential to follow the further CSI procedural steps.
To ensure that this new CSI procedure will become common practice, SoCOs need to be educated in operating CSIs with a Rapid DNA device. Deliberate practice will be a key factor in improving this process. This involves training through immediate feedback, time for problem-solving and evaluation, and having the opportunity for repeated practice to refine decision-making (5).

### 10.3.2 Decision Model

When in the previously explained CSI procedure it is decided to consider using the Rapid DNA device for intelligence purposes to identify a perpetrator, this decision can be guided by the Rapid DNA decision-model. This conceptual decision model was inspired by a scenario-driven DSS for serious crime investigation (6) and consists of the following stages:

1) The first stage consists of the 'hierarchy of decisions' where the crime and perpetrator relatedness of the detected traces are defined. In combination with the scientifically-based DNA success rates, the traces are ranked.
2) The highest ranked trace will follow the second stage of the DSS, where inferences on the type of case, time pressure, and additional traces are put into the system. In combination with the scientifically-based Rapid DNA success rates, the SoCOs are transparently guided through the decision process. This is achieved by explicitly considering the consequences of all possible outcomes.
3) In the third and final stage, the results of this decision process lead to deciding whether to use Rapid DNA on the trace or not.

The idea of this conceptual decision model is that the above-mentioned parameters can be assigned different weights, based on the case and trace characteristics. Through considering these several aspects in the model, this could lead to the decision to rapidly analyse a specific trace in one case; whereas, in another case, with other characteristics, it could be decided not to rapidly analyse a similar sort of trace.

To illustrate the effect of the Rapid DNA decision-model we will use two extreme examples. For instance, at the crime scene of a home robbery the following potential DNA traces were found: a crowbar, a fabric glove and a blood swipe. Based on the initially defined scenarios, the SoCO follows the first stage of the Rapid DNA decision-model: the 'hierarchy of decisions'. This stage guides the SoCO to rate both the crime relatedness and the perpetrator relatedness of the crowbar trace and the glove trace as extremely high. The crime relatedness of the blood swipe is also rated as extremely high, but the perpetrator relatedness is rated as extremely low. The system contains the scientifically based knowledge of DNA success rates: the fabric glove trace has a DNA success rate of 78%, the crowbar trace has a DNA success rate of 11% and the blood trace has a DNA success rate of 81%. This prior knowledge is combined with the inferences on the crime and perpetrator relatedness of the traces, and leads to the following ranking of the traces to potentially identify a perpetrator: 1) Fabric glove, 2) Crowbar and 3) Blood swipe. The fabric glove trace is therefore selected to follow the DSS in the second stage of the decision-model. In this stage, the SoCO rates the type of case as a violent home robbery, with a low expected time pressure of the perpetrator to strike again, and one additional perpetrator related trace was found that has not yet been analysed. Based on these inferences, this stage further guides the SoCO through considering and rating the consequences of all possible outcomes, taking alternative decisions for analysis of traces into account. All this knowledge is combined with the scientifically known *Rapid* DNA success rate of the glove trace of 66%. The final stage shows the outcome and leads to suggesting *not* to pursue Rapid DNA analysis on a sample of the fabric glove trace.

In another case, a violent home robbery occurred where the perpetrator took a machine gun, and the police suspect an imminent terrorist attack based on the defined initial scenarios. The complete process of the Rapid DNA decision-model is followed in the same way as explained above. However, in this case the time pressure of the case is extremely high, and the consequence(s) of all possible outcomes is rated differently when taking the alternative decisions for analysis into account. Therefore in this case, with the same sort of traces, the final stage suggests to decide to *pursue* Rapid DNA analysis on a sample from the glove trace to potentially identify the perpetrator.

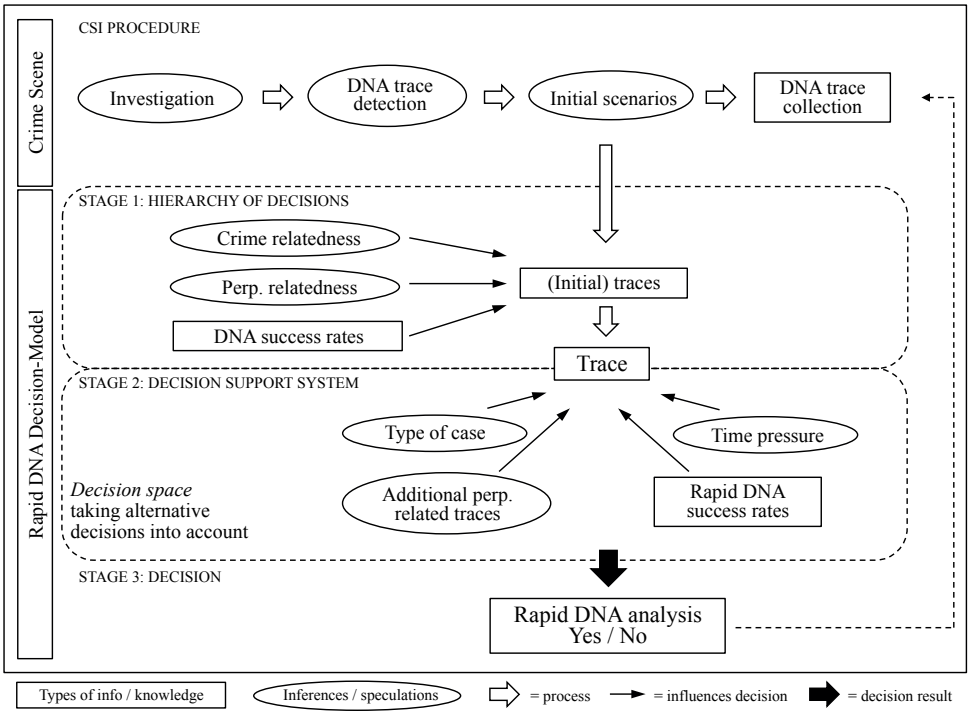



**Figure 2.** Rapid DNA Decision Model

## 10.4 Future Perspectives - The Way Forward

To implement state-of-the-art Rapid DNA technology a thought-out decision model, clear protocols, and training through deliberate practice are essential to get full acceptance by the professionals from the criminal justice chain. Forensic science and crime scene practice will become more and more intertwined. This thesis serves as the foundation for this future perspective of mobile Rapid DNA technologies at the crime scene. This should not be considered a threat for forensic institutes and their scientists,

but should be embraced as the new forensic future. Through integrating science and practice the throughput of criminal investigations could speed up - where 'simple' routine analysis is performed by the police, and forensic scientists focus on expert analysis - where data is shared and decisions are made together: entering the era of *forensic science and crime scene practice connected.*

*Rapid DNA technologies at the crime scene: 'CSI' fiction matching reality*

## 10.5 References


1. Justitie MVe. Besluit van 26 maart 2012, houdende inwerkingtreding van de wet van 24 november 2011 tot wijziging van het Wetboek van Strafvordering en de Wet DNA-onderzoek bij veroordeelden in verband met de introductie van DNA-verwantschapsonderzoek en DNA-onderzoek naar uiterlijk waarneembare persoonskenmerken van het onbekende slachtoffer en de regeling van enige andere onderwerpen (Stb. 2011, 555). Retrieved from: https://wwweerstekamernl/behandeling/20120329/publicatie_inwerkingtreding_2/document3/f=/viy8fe yfmhmwpdf. 2012.
2. Woods D, Dekker S. Anticipating the effects of technological change: a new era of dynamics for human factors. Theoretical issues in ergonomics science. 2000;1(3):272-82.
3. Gruijter M. *The influence of rapid identification technologies on CSI behaviour*. Amsterdam;PhD thesis Amsterdam University of Applied Science: 2017.
4. LocalDNA: DNA-onderzoek op locatie Van laboratorium naar opsporingspraktijk. 2017. Retrieved from : https://www.nwo.nl/onderzoek-en-resultaten/onderzoeksprojecten/i/64/27964.html
5. Anders Ericsson K. Deliberate practice and acquisition of expert performance: a general overview. *Academic Emergency Medicine,* 2008;15(11):988-94.
6. Shen Q, Keppens J, Aitken C, Schafer B, Lee M. A scenario-driven decision support system for serious crime investigation. *Law, Probability and Risk,* 2006;5(2):87-117.

# Epilogue

**List of publications**

**Samenvatting/Dutch Summary**

**Acknowledgements/dankwoord**

**Curriculum Vitea**

# List of Publications

Mapes A, Poot de C, Kloosterman A. De rol van DNA bij het vinden van een dader. *Tijdschrift voor Criminologie*, 2014:*56*(3), 29-46.

Mapes AA, Kloosterman AD, & Poot de CJ. DNA in the criminal justice system: the DNA success story in perspective. *Journal of forensic sciences*, 2014:*60*(4), 851-856.

Mapes A. DNA by the Numbers - Locations of usable DNA based on 24,466 crime scene samples. *Forensic Magazine,* 2015;12(5):8-9.

Mapes AA, Kloosterman AD, Marion van V, Poot de CJ. Knowledge on DNA success rates to optimise the DNA analysis process: from crime scene to laboratory. *Journal of Forensic Sciences*, 2016:*61*(4), 1055-1061.

Mapes AA, Kloosterman AD, Poot de CJ, Marion van V. Objective data on DNA success rates can aid the selection process of crime samples for analysis by rapid mobile DNA technologies. *Forensic Science International,* 264: 28-33.

Mapes AA, Poot de CJ. Rapid DNA analysis at a mock crime scene - The impact on collecting and analysing DNA traces. Accepted for publication in *Journal of Forensic Sciences.*

Mapes A, Noordam N. Mobiele DNA-technieken bij de forensische opsporing: het juridisch kader. *Expertise en Recht,* 2015;3:88-95.

Mapes AA, Stoel RD, Poot de CJ, Vergeer P, Huyck M. Decision Support for using mobile Rapid DNA analysis at the crime scene. Under review at *Science & Justice.*

Kloosterman A, Mapes A, Geradts Z, Eijk van E, Koper C, Berg van den J, Verheij S, Steen van der M, Asten van A. The interface between forensic science and technology: how technology could cause a paradigm shift in the role of forensic institutes in the criminal justice system. *Philosophical Transactions of the Royal Society B*, 2015:370(1674); 2014.0264.

# **Samenvatting** (summary in Dutch)

## ‘Rapid DNA Technologies at the Crime Scene: ‘CSI’ fiction matching Reality’

Snelle en mobiele DNA-analyse (Rapid DNA) van sporen is al jaren een ‘standaard’ procedure in de welbekende serie ‘CSI’, om daders mee op te sporen. Deze serie is duidelijk fictie, maar is mogelijk een serieuze blik naar het toekomstig forensisch onderzoek. In de afgelopen jaren zijn er vele studies geweest naar het creëren van een volledig geïntegreerd DNA-analyse systeem met als doel het DNA-onderzoek te versnellen. Het streven van deze ontwikkeling is dat de Forensisch Onderzoeker (FO’er) al op de plaats delict een bemonstering van een spoor kan analyseren, middels Rapid DNA, om binnen enkele uren potentieel identificerende resultaten te ontvangen. Echter brengt deze Rapid DNA-technologie ook risico’s met zich mee. Zo kan de focus van de FO’ers tijdens het sporenonderzoek wijzigen, door bijvoorbeeld meer ‘opzoek’ te gaan naar DNA-sporen, wanneer zij deze techniek tot hun beschikking hebben. Daarbij komt ook dat de techniek minder gevoelig is dan de technieken op het forensisch laboratorium. Hiermee bestaat het risico dat er DNA-sporen geanalyseerd worden met Rapid DNA die geen DNA-profiel opleveren terwijl hetzelfde spoor in het lab wel tot een DNA-profiel had geleid.

Verwacht wordt dat deze baanbrekende ontwikkeling zal leiden tot een fundamentele verandering voor de forensische opsporing, het forensisch laboratorium en het openbaar ministerie. Om er zeker van te zijn dat opsporing en vervolging optimaal zullen profiteren van deze Rapid DNA-technologie is het van essentieel belang te onderzoeken hoe deze techniek zo efficiënt mogelijk ingezet kan worden op de plaats delict om geaccepteerd te worden binnen de strafrechtsketen. De volgende drie factoren zijn onmisbaar in de analyse naar deze kwestie: 1) de technische mogelijkheden van Rapid DNA, 2) het gedrag van de gebruikers op de plaats delict wanneer Rapid DNA-beslissingen genomen moeten worden, en 3) de juridische mogelijkheden om Rapid DNA op de plaats delict uit te voeren. De uitdaging in dit onderzoek is dat er een koppeling gemaakt moet worden tussen de technologische implicaties, de gedragsimplicaties en de juridische implicaties die aan het gebruik van Rapid DNA op de plaats delict ten grondslag liggen. Deze kennis is vereist om procedurele, contextuele en besluitvormingsprocessen voor het gebruik van Rapid DNA te begrijpen om aanbevelingen te kunnen doen voor toekomstig DNA-onderzoek.

Om de analyse naar de impact van Rapid DNA op de plaats delict uit te voeren zijn acht studies verricht die bovengenoemde implicaties in kaart brengen en koppelen. Deze studies worden in de volgende zeven paragrafen behandeld en afgesloten met een toekomstig perspectief van Rapid DNA op locatie.

## 1. DNA als Opsporingsmiddel

In de eerste studie (Hoofdstuk 2) is middels een dossieronderzoek analyse gedaan naar de rol van DNA als opsporingsmiddel. De resultaten laten zien dat in 1% van de High Volume Crime (HVC) -zaken en in 3% van de Ernstige Delict (ED) -zaken, die door een FO'er zijn onderzocht, een match in de DNA-databank heeft geleid tot het opsporen van een tot dan toe nog onbekende verdachte. Daarbij kwam naar boven dat 17% van de geanalyseerde HVC-sporen en 38% van de geanalyseerde ED-sporen geen DNA-profiel opleverden. Deze DNA-onderzoeken lieten relatief lange doorlooptijden zien van plaats delict tot DNA-rapportage.

In een aantal zaken werd een verdachte zelfs opgespoord door andere opsporingsmethoden voordat de DNA-match bekend werd. In deze situaties verliest DNA-onderzoek als opsporingsmiddel zijn potentie.

Verwacht wordt dat in zaken waar voldoende DNA-materiaal aanwezig is, Rapid DNA als opsporingsmiddel gebruikt kan worden en zal leiden tot het verhogen van het rendement van DNA-onderzoek en het versnellen van het identificeren van nog onbekende verdachten. Deze versnelling kan leiden tot het staken van andere (tijdrovende) opsporingsmethoden zoals het uitvoeren van buurtonderzoek, het analyseren van telecommunicatiedata, of het uitlezen van bewakingscamera's.

## 2. Technologische Implicaties – DNA-kansrijkheid

Rapid DNA-analyse is minder gevoelige dan laboratoriumanalyse en het geanalyseerde monster dient als verbruikt beschouwd te worden. Dit impliceert dat kennis van DNA-kansrijkheid van sporen van essentieel belang is om weloverwogen beslissingen te kunnen nemen om Rapid DNA in te zetten of niet. De tweede en derde studie in dit proefschrift (Hoofdstuk 3 en 4) richten zich daarom op het definiëren van DNA-kansrijkheden van een verscheidenheid aan sporen. Middels een grootschalig dossieronderzoek zijn geanalyseerde DNA-monsters van 28 verschillende spoorcategorieën geëvalueerd. De resultaten laten zien dat de helft van de DNA-sporenmonsters te weinig DNA bevatte om (bruikbare) DNA-profielen te genereren. Er werd een positieve relatie gevonden tussen de kansrijkheid en de DNA-concentratie. Dit bleek onafhankelijk van het type sporenmonster. Het integreren van een drempelwaarde op basis van DNA-concentratie zou daarom de DNA-analyseprocedure op het laboratorium kunnen optimaliseren. Op deze manier kan er meer gefocust worden op het analyseren van meer kansrijke DNA-sporen en zal het nodeloos analyseren van 'lege' DNA-sporen dalen.

In meer detail, lieten de studies verder zien dat monsters van peuken, bloed en hoofddeksels een relatief hoge DNA-kansrijkheid hebben, terwijl monsters van patroonhulzen, gereedschap, tape en tie-wraps het minst kansrijk bleken (zie Tabel 3, pg. 62). Deze informatie heeft geleid tot het opzetten van een spoor specifiek DNA-kansrijkheidsmodel om FO'ers te kunnen assisteren bij het prioriteren en selecteren van

DNA-sporen voor analyse. In dit model is een vier-stappen besluitvormingsproces gedefinieerd: 1) stel bewijswaardige sporen veilig, 2) rangschik de sporen op basis van misdaad- en/of dader-gerelateerdheid, 3) gebruik de DNA-kansrijkheidstabel, 4) selecteer het meest belovende spoor voor DNA-analyse.

## 3. Technologische Implicaties – Rapid DNA en het DNA Kansrijkheidsmodel

In de vierde studie (Hoofdstuk 5) is de opgedane kennis over DNA-kansrijkheid gebruikt om ondersteuning te bieden aan het prioriterings- en selectieproces van sporen voor Rapid DNA-analyse. Deze studie liet zien dat minder gevoelige DNA-analyses een significant effect hebben op de kansrijkheid van DNA-sporen. Deze kennis is van cruciaal belang om het potentieel verlies van belangrijke sporen door Rapid DNA-analyse, te minimaliseren. Sporen met een lage DNA-concentratie zijn daarom minder geschikt voor Rapid DNA-analyse. Sporen die een hoge kansrijkheid op het laboratorium laten zien bieden daarmee ook de hoogste potentie voor Rapid DNA.

Rapid DNA kan dus nog niet wedijveren met de analysemogelijkheden die het laboratorium biedt, maar het kan wel leiden tot cruciale opsporingsinformatie binnen twee uur. Om FO'ers te assisteren in het besluit om een DNA-spoor te analyseren middels Rapid DNA, is daarom een relatief eenvoudig kansrijkheidsmodel ontwikkeld dat met elke DNA-concentratiedrempelwaarde om kan gaan (zie Figuur 1, pg. 76). Dit model laat zowel de laboratorium- als de Rapid DNA-kansrijkheid van een spoor zien bij de specifieke drempelwaarde. Hierdoor geeft dit model dus inzicht in de kans op een 'fout-negatief' resultaat dat gebruikt kan worden om de afweging voor Rapid DNA te maken.

Deze informatie kan opgenomen worden in het vier-stappen besluitvormingsproces en FO'ers begeleiden in de keuze voor Rapid DNA op de plaats delict of het spoor door te sturen voor analyse naar het laboratorium.

## 4. Gedragsimplicaties

Nu de technologische implicaties van Rapid DNA bekend zijn moet er getest worden wat voor effect dit heeft voor het toekomstige forensisch onderzoek en het besluitvormingsproces van de FO'er. In de vijfde studie (Hoofdstuk 6) is daarom middels een 'real-life' observatiestudie met 40 FO'ers onderzocht wat de gedragsimplicaties zijn als Rapid DNA wordt geïntegreerd. Alle FO'ers onderzochten een geënsceneerde plaats delict van een gewelddadige overal, met of zonder een Rapid DNA-optie. De resultaten van deze studie impliceren dat een misdrijf sneller opgelost kan worden met Rapid DNA. Echter, wanneer de FO'ers Rapid DNA tot hun beschikking hadden, werden er significant meer sporen geselecteerd voor DNA-analyse. Deze sporen waren vaak slachtoffer-gerelateerd, waarvan de meesten niet een link hadden met het misdrijf, in ons scenario. Opvallend was dat de sporen die geanalyseerd werden met Rapid DNA overwegend contactsporen of interdisciplinaire sporen betrof.

De studie liet verder zien dat FO'ers een incorrect beeld hebben van DNA-kansrijkheid van verschillende DNA-sporen en hiermee het risico lopen om informatieve maar kansarme DNA-sporen te analyseren met Rapid DNA. DNA-kansrijkheid werd daarbij nauwelijks meegnomen in de beslissing het spoor met Rapid DNA te analyseren. Deze studie maakt duidelijk de behoefte kenbaar om een extensief raamwerk te ontwikkelen die het besluitvormingsproces voor de selectie van DNA-sporen voor analyse kan ondersteunen.
De inzichten in deze gedragsimplicaties hebben geleid tot het uitbreiden van het vier-stappen besluitvormingsproces tot een 'Hiërarchie van Beslissingen' voor Rapid DNA:

1) Detecteer en stel alle relevante sporen veilig,
2) rangschik de sporen op basis van misdaad-gerelateerdheid,
3) rangschik de veronderstelde misdaad-gerelateerde sporen op basis van dader-gerelateerdheid,
4) gebruik de Rapid DNA-kansrijkheidsfiguur voor verdere selectie,
5) selecteer het meest belovende spoor voor Rapid DNA-analyse,
6) heroverweeg alle veiliggestelde sporen in het licht van verschillende scenario's met het onderzoeksteam, na het forensisch onderzoek,
7) besluit voor eventuele verdere DNA-analyses.

De heroverwegingsstap (stap 6) moet ervoor zorgen dat de FO'er zijn forensisch onderzoek op de plaats delict, de analysebeslissingen en de vervolgstappen grondig evalueert. Wanneer Rapid DNA heeft geleid tot het identificeren van een verdachte is het van cruciaal belang alle andere sporen te (her)overwegen die mogelijk de dader(s) kunnen identificeren of die inzicht kunnen geven in hoe het misdrijf is gepleegd. Dit kan mogelijk leiden tot een meer transparant en doordacht besluitvormingsproces voor de analyse van sporen wanneer Rapid DNA een optie is.

## 5. Juridische Implicaties

De zesde studie (Hoofdstuk 7) richt zich op de analyse naar de huidige juridische (on)mogelijkheden voor het gebruik van Rapid DNA op de plaats delict door een FO'er. De huidige wet- en regelgeving is tweeledig. Enerzijds kan er geconcludeerd worden dat Rapid DNA zonder specifieke wettelijke grondslag voor het opsporingsonderzoek kan worden ingezet. Anderzijds kan de uitslag van een Rapid DNA-analyse niet worden gebruikt voor de bewijsvoering in strafzaken. Hiervoor moet het spoor in behandeling worden genomen door en een analyse ondergaan bij een aangewezen geaccrediteerd laboratorium. Dit beletsel zou weggenomen kunnen worden door Rapid DNA in te passen in de huidige wet- en regelgeving, bijvoorbeeld door bij het DNA-onderzoek op locatie een DNA-deskundige te betrekken die is verbonden aan een bij algemene maatregel van bestuur aangewezen laboratorium en daarbij de Rapid DNA-techniek en

de procedure voor het gebruik daarvan te accrediteren. Een andere optie is het aanpassen van de wetgeving.
De juridische analyse laat verder zien dat in de procedure van het toekomstig gebruik van Rapid DNA bij de politie de volgende waarborgen behandeld moeten worden: 1) officier van justitie is de bevoegde autoriteit, 2) invoering van een regeling met waarborgen waaraan apparaat moet voldoen, 3) invoering protocol voor inzet van type DNA-sporen, 4) FO'ers krijgen extra scholing, 5) contra-expertise blijft mogelijk, en 6) situatie op de plaats delict en vervolgtraject worden goed vastgelegd.

## 6. Beslis-ondersteunend-model

Met een Rapid DNA-optie moet de FO'er ter plaatse een beslissing nemen om enerzijds een monster van een relevant DNA-spoor binnen twee uur te analyseren met de minder gevoelige Rapid DNA-techniek, of anderzijds het spoor door te sturen naar het laboratorium voor analyse met de beste technologie maar met een (veel) langere doorlooptijd. Om een optimaal besluit te kunnen nemen moeten beide aspecten systematisch worden gedefinieerd. Om deze reden is de focus van de zevende studie (Hoofdstuk 8) het ontwikkelen en testen van een beslis-ondersteunend-model, ook wel 'Decision Support System (DSS)' genoemd, waarbij alle implicaties worden gekoppeld en de FO'ers begeleid worden in het besluit Rapid DNA wel of niet in te zetten op een spoor.
In deze studie is op basis van Rationele Besliskunde een specifiek Rapid DNA beslis-ondersteunend-model ontwikkeld. In dit model worden FO'ers gedwongen alle mogelijke uitkomsten en de consequenties te overwegen die vervolgens in het model gekoppeld worden aan Rapid DNA-kansrijkheid. Op deze manier worden zowel mogelijkheden als risico's geëxpliciteerd voordat een beslissing wordt bereikt.
Middels een vignetten-studie waar een casus op papier werd geschetst is dit model getoetst, FO'ers moesten aan de hand van deze casus beslissen Rapid DNA in te zetten in een moordzaak of inbraakzaak. Hierbij werden ze begeleid middels het beslis-ondersteunend-model of niet. De resultaten lieten zien dat het model niet door iedereen op de juiste wijze werd gebruikt en verdient daarom nog verdere ontwikkeling. Echter, liet de studie ook zien dat, ondanks het vorig genoemde resultaat, de FO'ers andere en meer doordachte beslissingen namen in het gebruik van Rapid DNA wanneer ze begeleid werden door het beslis-ondersteunend-model. De beslissing om Rapid DNA in te zetten werd significant beïnvloed door de factoren 'tijdsdruk' en 'spoorkarakteristieken' zoals DNA-kansrijkheid. Dit geeft aan dat toekomstig forensisch onderzoek op de plaats delict baat kan hebben bij zo'n beslis-ondersteunen-model, met name wanneer dit gecombineerd zou worden met de 'Hiërarchie van Beslissingen'.

### 7. De Toekomst van Rapid DNA op de Plaats Delict

De achtste en laatste studie van dit proefschrift (Hoofdstuk 9) concludeert dat het strafrechtssysteem een sterke intrinsieke motivatie heeft om snel forensische analyseresultaten te verkrijgen die kunnen leiden tot het sneller opsporen van verdachten, sneller oplossen van misdaden en die de juridische procedure efficiënter maken. Door de technologische mogelijkheden en ontwikkelingen van Rapid DNA wordt er verwacht dat de rol van forensische instituten zal veranderen. Het toekomstig perspectief is om geïntegreerde forensische platforms te creëren waar forensische expertise en de politiepraktijk worden geïntegreerd.

### Conclusie

Door een weloverwogen juridische basis, extensieve kwaliteitscontroles en een doordacht beslismodel zal de 'state-of-the-art' Rapid DNA-technologie van meerwaarde zijn voor het strafrechtssysteem. Forensische wetenschap en forensisch onderzoek in de politiepraktijk zullen meer en meer met elkaar verweven worden. Dit proefschrift dient als een grondslag voor het toekomstige perspectief van mobiele Rapid DNA-technologieën op de plaats delict. Door het integreren van wetenschap en praktijk kan de doorloop van het misdaadonderzoek worden versneld – waar 'simpele' routinematige analyses worden uitgevoerd door de politie en forensisch wetenschappers focussen op expertanalyses – waar data wordt gedeeld en beslissingen samen worden genomen: de start van een nieuw tijdperk waar *forensische wetenschap en politiepraktijk zijn verbonden.*

*Rapid DNA technologies at the crime scene: 'CSI' fiction matching reality*

## Rapid DNA in de Praktijk

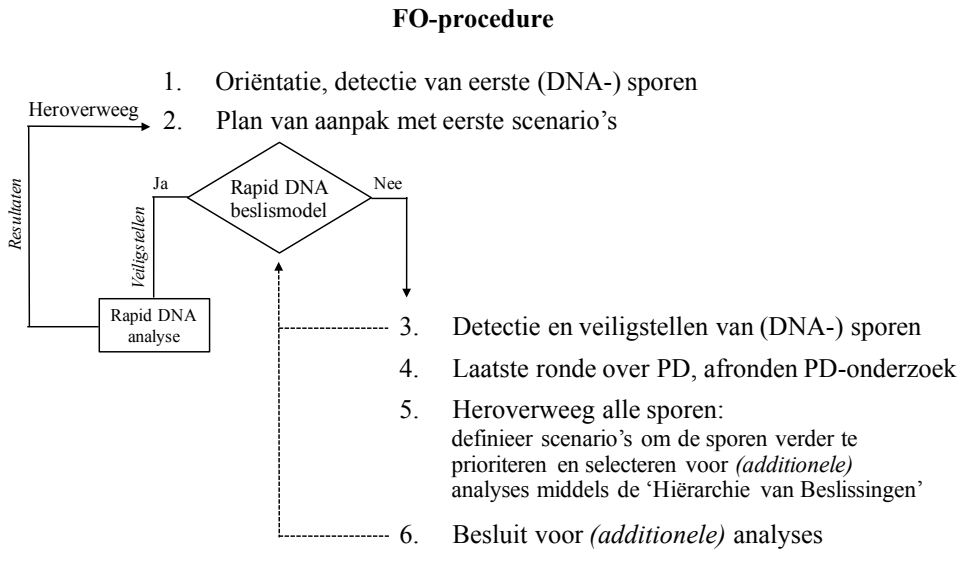
De resultaten uit de studies in dit proefschrift hebben ertoe geleid een conceptuele Forensisch Onderzoek (FO)-procedure en Rapid DNA Beslismodel te ontwikkelen om de toekomstige integratie van Rapid DNA te faciliteren in de politiepraktijk. Deze concepten kunnen gebruikt worden als prototypen in het begeleiden van toekomstige besluiten om Rapid DNA wel of niet in te zetten op de plaats delict en worden in de volgende twee paragrafen behandeld. Het is belangrijk om te realiseren dat de kennis voor deze conceptuele processen actueel gehouden wordt en nieuwe kennis verzameld wordt om het beslismodel verder te optimaliseren.

### FO-procedure

Wanneer Rapid DNA geïntegreerd wordt op de plaats delict, zal het standaard 4-fasemodel voor forensisch onderzoek aangepast moeten worden. In het huidige proces van misdaadonderzoek zijn de processen van spoordetectie, prioriteren en selecteren, de

analyses en de uiteindelijke interpretatie van resultaten, gescheiden procedures. De Rapid DNA-optie zal leiden tot een integratie van al deze stappen op de plaats delict. Daarom wordt het aangeraden het 4-fasemodel voor forensisch onderzoek uit te breiden naar een adaptieve FO-procedure (zie ook Figuur 1):

1. Oriëntatie en potentiële detectie van de eerste zichtbare (DNA-) sporen.
2. Plan van aanpak en definiëren van eerste scenario's.
   In deze stap zou het gebruik van Rapid DNA al direct overwogen kunnen worden. Dit kan leiden tot het continueren van de standaardprocedure of het volgen van de Rapid DNA-procedure (door het gebruik van een beslismodel, zie volgende paragraaf). Na veiligstellen van het specifieke spoor en de inzet van Rapid DNA, kunnen de resultaten leiden tot nieuwe informatie die mogelijk resulteren in het herzien van het plan van aanpak. Het continue heroverwegen van het plan van aanpak is een fundamenteel nieuw element in de voorgestelde FO-procedure.
3. Detecteren, veiligstellen en documentatie van alle gelokaliseerde sporen op de plaats delict.
   Deze stap kan wederom reden zijn om te besluiten Rapid DNA in te zetten en het plan van aanpak te heroverwegen.
4. Laatste ronde over de plaats delict uitvoeren.
5. Heroverweeg alle veiliggestelde sporen in combinatie met alle verzamelde informatie om finale scenario's te definiëren met het onderzoeksteam, forensisch analisten en experts.
6. Prioritering van de sporen en potentiele selectie voor verdere Rapid DNA of laboratorium DNA-analyse.
   Deze stap kan wederom reden zijn om Rapid DNA in te zetten en het plan van aanpak te heroverwegen.

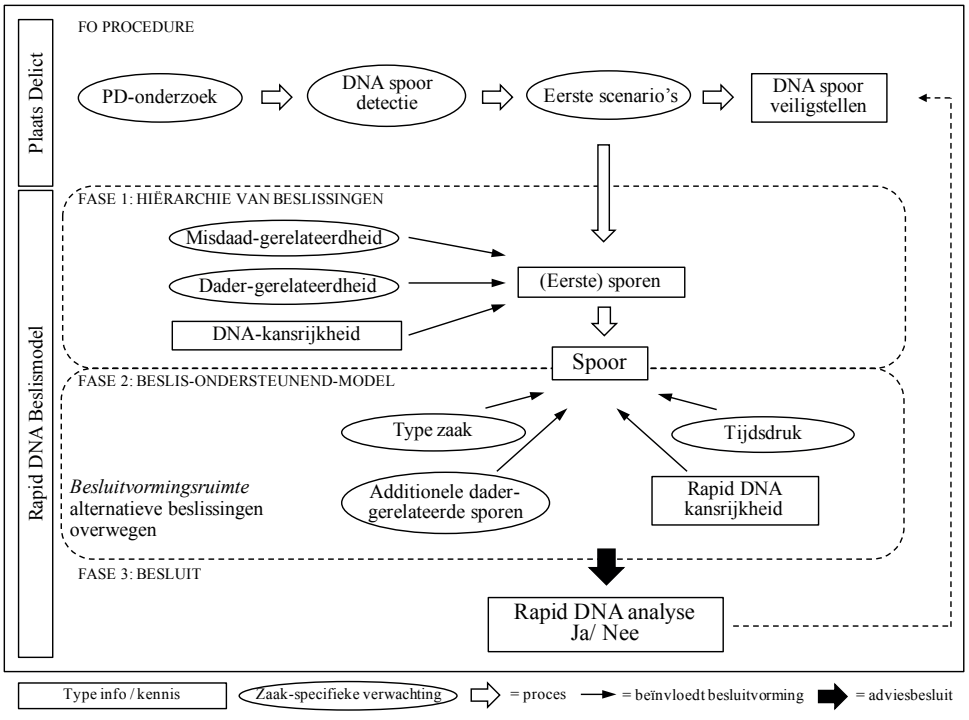



**Figuur 1.** Hernieuwde FO-procedure voor (DNA-) spooranalyses

## Rapid DNA Beslismodel

Wanneer middels de FO-procedure overwogen wordt Rapid DNA in te zetten voor opsporingsdoeleinden kan de definitieve beslissing begeleid worden door het Rapid DNA Beslismodel (zie ook Figuur 2):

1. De eerste fase bestaat uit de 'Hiërarchie van Beslissingen' waar de misdaad- en dader-gerelateerdheid van het gedetecteerde spoor worden gedefinieerd. In combinatie met de wetenschappelijk onderbouwde kennis over DNA-kansrijkheid worden de sporen gerangschikt.
2. Het spoor bovenaan deze rangschikking volgt de tweede fase van het beslismodel waar gedachten over het type zaak, de tijdsdruk en eventuele additionele sporen in het systeem ingevoerd worden. In combinatie met de wetenschappelijk onderbouwde kennis over *Rapid* DNA-kansrijkheid worden de FO'ers transparant begeleid door het besluitvormingsproces. Dit wordt bereikt door expliciet alle consequenties en mogelijke uitkomsten uit een te zetten.
3. In de derde en laatste fase zal het resultaat van het besluitvormingsproces leiden tot een advies om Rapid DNA op het geselecteerde spoor in te zetten of niet.




**Figuur 2.** Rapid DNA Beslismodel

Het idee van dit conceptuele Rapid DNA Beslismodel is dat aan bovengenoemde parameters verschillende gewichten toegekend kunnen worden, gebaseerd op zaaks- en spoorkarakteristieken. Door het in acht nemen en overwegen van deze aspecten in het model, kan dit leiden tot het besluit Rapid DNA in te zetten op een specifiek spoor in de ene zaak, terwijl in een andere zaak, met andere karakteristieken, er besloten kan worden een vergelijkbaar spoor niet voor Rapid DNA in te zetten. Zie voor een illustratief voorbeeld het kader hieronder.

**Voorbeeld**

Om het effect van het Rapid DNA Beslismodel te illustreren zullen we gebruik maken van twee extremen. Bijvoorbeeld, op de plaats delict van een woningoverval worden de volgende potentiële DNA-sporen gevonden: een breekijzer, een stoffen handschoen en een bloedveeg. Gebaseerd op de eerste gedefinieerde scenario's volgt de FO'er de eerste fase van het beslismodel: de 'Hiërarchie van Beslissingen'. Deze fase begeleidt de FO'er om zowel de misdaad-gerelateerdheid als de dader-gerelateerdheid van het breekijzerspoor als het handschoenspoor als extreem hoog te waarderen, in deze specifieke casus. De misdaad-gerelateerdheid van het bloedspoor is ook extreem hoog, maar de dader-gerelateerdheid wordt gewaardeerd als extreem laag, in dit voorbeeld. Het beslissyteem bevat de wetenschappelijke kennis van DNA-kansrijkheid: een spoor van de stoffen handschoen heeft een DNA-succeskans van 78%, een spoor van het breekijzer heeft een DNA-succeskans van 11% en het bloedspoor heeft een DNA-succeskans van 81%. Deze kennis wordt vervolgens gecombineerd met zaak-specifieke verwachtingen over de misdaad- en dader-gerelateerdheid van de sporen en leidt tot de volgende rangschikking: 1) stoffen handschoen, 2) breekijzer en 3) bloedveeg. De stoffen handschoen wordt als spoor geselecteerd om vervolgens het beslis-ondersteunend-model te volgen in de tweede fase van het Rapid DNA Beslismodel. In deze fase waardeert de FO'er de zaak als een gewelddadige overval met een lage verwachte tijdsdruk dat de dader potentieel op korte termijn opnieuw toeslaat, en de FO'er geeft aan dat er een ander dader-gerelateerd spoor is dat nog niet is geanalyseerd. Gebaseerd op deze zaak-specifieke verwachtingen, begeleidt deze fase de FO'er verder door de consequenties van alle mogelijke uitkomsten van een besluit, door alternatieve scenario's voor DNA-analyse van het spoor te behandelen. Al deze kennis wordt gecombineerd met de wetenschappelijke kennis van *Rapid* DNA-kansrijkheid van het handschoenspoor dat een DNA-succeskans heeft van 66%. De finale fase laat de uitkomst zien en leidt tot het advies om Rapid DNA *niet* in te zetten op een monster van het handschoenspoor.

In een ander zaak, waar ook een woningoverval is gepleegd en bekend is dat de dader een mitrailleur heeft meegenomen verwacht de politie mogelijk een terroristische aanslag, op basis van de eerste gedefinieerde scenario's. Het complete proces van het Rapid DNA Beslismodel wordt op exact dezelfde manier uitgevoerd als hierboven is uitgelegd. Echter, in deze zaak is de tijdsdruk van de zaak als extreem hooggewaardeerd en de consequenties van alle mogelijke uitkomsten zijn anders gewaardeerd bij het behandelen van alternatieve scenario's voor DNA-analyse van het spoor. Daarom wordt er in deze zaak, met dezelfde soort sporen, in de finale fase het advies gegeven *wel* Rapid DNA in te zetten op een monster van het handschoenspoor om potentieel de dader mee te kunnen identificeren.

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*Anna*

# Curriculum Vitea

Anna Mapes (12 april 1988, Taunton UK) started her study with the Bachelor Psychobiology in 2006. This was followed by the Master Forensic Science in 2010. During her master's she performed an internship at the 'Kennemerland' police forensics department where she worked on analysing the potential impact of mobile DNA technologies at the police. In August 2012 she graduated at the University of Amsterdam and started as a PhD-candidate within the research program 'Bringing Science to the Crime Scene' (Beter Opsporen met het Lab op zak) at the Forensic Science research group of the Amsterdam University of Applied Sciences. Her PhD-research, towards Rapid DNA technologies at the Crime Scene led to a collaboration with the Forensic Identification Division of the New York City Police Department to work on designing a Rapid DNA support system for forensic investigators. During her PhD-research years a Rapid DNA working group, called LocalDNA was set up, of which she is one of the leading members. This group is a collaboration of the Netherlands Forensic Institute, the Dutch Police Force, the Public Prosecution Service and the Forensic Science research department of the Amsterdam University of Applied Sciences. LocalDNA is focussed on researching and creating working methods for potential Rapid DNA analysis in the Netherlands. In 2016 the LocalDNA project was acknowledged with the RAAK-Publiek scholarship to financially support the LocalDNA project. In the same year, the overall research program, of which her PhD research was part, was awarded with the RAAK-Award (3$^{rd}$ place). The prize is awarded to leading applied research projects at Dutch universities of applied sciences (Hogescholen), funded by the 'Stichting Innovatieve Alliantie' (SIA). In April 2017 she was appointed as researcher and project leader LocalDNA at the Amsterdam University of Applied Sciences. In December 2017 she will combine here current job with working at the Dutch Police Force as a Forensic Advisor.