Forensic Labscan

Examining the Examination: Improving Efficiency in Forensic Laboratories

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Abstract—**Crimes involving weapons have increased in the Netherlands by 24 per cent in the past ten years, while the decrease in reported crimes has stabilised since 2018. Given that crimes with weapons are often complex and are often investigated in a multidisciplinary manner, these trends increase the demands for complex investigations within the Dutch justice system and, therefore, on the Netherlands Forensic Institute (NFI) as well. Here, the department of Human Biological Traces (BiS) examines evidentiary pieces ("Stukken Van Overtuiging', SVOs), such as knives, to find human biological traces, a process that is called the preliminary examination. The preliminary examination is labour-intensive, and with the increasing demands, could benefit from an optimised workflow. However, to identify and improve issues with the workflow, the workflow needs to be known. In this observational study, all actions during the preliminary examination were observed and measured. These data were used to determine the duration of SVO examinations and laboratory sessions, their parts and their occurrences. The median duration of a laboratory session was 69 minutes, and the median duration of a completed SVO examination was 29 minutes. The duration of an SVO examination is affected by the category of the SVO, the difficulty level of the examination and the research question. Issues of the workflow were categorised as solvable in the short and long term. In the short term, the workflow could be improved by better managing materials and electronic devices. Furthermore, Processing sample kits could be less labour-intensive by adding codes to the sample containers and performing the examination on a work surface with ridges. The availability and reachability of experts may be improved by aligning their availability with the examination. By solving the bottlenecks concerning material management and processing sample kits, respectively, 15.9 and 56.7 hours per year could be won based on the examinations performed in 2024. In the long term, administrative tasks and examinations with the Crime-lite need further research to provide insights to save time.**

1. Introduction

The number of crimes involving weapons has increased in the past ten years by 24 per cent. Knives and such are often investigated in a multidisciplinary manner, which adds to the complexity of crime cases as it involves analysis of fingerprints and DNA [2]. Another trend is a decrease in the total number of reported crimes between 2011 and 2018, but the incidence has since then stabilised. This combination of crime trends shifts the demands of the Dutch Justice system, with more resources needed for complex cases.

In the Dutch justice system, the Public Prosecution Service ("Openbaar Ministerie", OM) is responsible for the investigation and prosecution of criminal offences [3], while the police investigate crime scenes and track down potential suspects. In some cases, the police also conduct the entire basic preliminary examination themselves: they collect and secure biological traces (such as contact DNA, blood, semen, or saliva) from the evidentiary pieces ("Stukken van overtuiging", SVOs), and perform DNA isolation to determine whose DNA it is. However, most of these preliminary examinations are performed by the Netherlands Forensic Institute (NFI), especially when they are more complex or multidisciplinary [4]. The NFI is a centre for forensic research, with almost forty forensic disciplines. Apart from the preliminary examination, they can also perform postmortem autopsies, examine non-human fibres and examine digital evidence [5]. A typical SVO that the police will not examine themselves but send to the NFI is a knife found at the crime scene: the knife can be examined for the presence of fingerprints and blood, as well as

for DNA analysis.

The budget of the Dutch Justice system must be allocated wisely, given the increase in more complex cases without a corresponding decrease in crime rates, and is under the purview of the Ministry of Justice and Security. The Ministry of Justice and Security divides the budget among various agencies, including the OM, the Immigration and Naturalisation Service (IND), and the NFI.

To make the most of the budget and other capacities, the OM sets a priority for each case based on its nature to determine the order of investigations. Offences with, for example, physical harm to victims are prioritised over cases such as tanking without paying [6]. Furthermore, the processing times due to backlogs are lengthy, making it difficult for victims as they have to wait for justice [7].

As the number of complex cases increases and the OM prioritises cases involving physical harm to victims, the workload of the NFI also increases. Although some automation has been introduced, such as automated DNA quantification and profile generation, most processes, including laboratory and administrative work, remain labour-intensive. This does not help with the high caseload. Case backlogs and pressure to be fast are major factors that increase stress, which negatively impacts examiners [8, 9]. To handle its workload, the NFI makes Service Level Agreements (SLAs) with the OM to limit the number of cases it receives [10]. Furthermore, the trends in crime are also incorporated in the SLAs: the NFI can adjust its capacity and priorities in response to the trends.

The division of the NFI that focuses on human biological traces ("Biologische Sporen", BiS) performs preliminary examinations on SVOs to determine whether and what kind of human biological traces can be found. The examiners of the SVO do this by developing a plan based on the research question belonging to the SVO and detecting, collecting and securing the biological traces. Furthermore, to maintain the chain of custody for the SVOs, they also photograph and document every step. All these steps are labour-intensive. Due to an insufficient understanding of the process and its bottlenecks, it is difficult to improve it effectively through technology or other means. Because of these properties, the preliminary examination by BiS was chosen for analysis, as there is still much to gain compared to DNA analysis, since more automation is involved [11, 12, 13, 14, 15].

The preliminary investigations entail the following: SVOs are collected from either the victim, the suspect, or the crime scene and sent to the NFI. Human biological traces need to be found, collected, and analysed. Human biological traces can include contact DNA, RNA, blood, semen, or saliva. While new personnel are being trained at the NFI, which takes at least two years, a structural capacity shortage will persist due to the increasing complexity of cases. It would be beneficial for the NFI to reduce the time required for their tasks, and this would also help reduce backlogs.

Due to its high workload and labour-intensive examinations, BiS potentially has much to gain from improving its processes. Ideally, this would make the process less time-consuming while preserving the quality of the work. Yet, without a clear understanding of the detailed workflow, it is difficult to pinpoint problems and address them. A workflow analysis is a method that can be used to analyse and improve a process by fully understanding the workflow during the process and analysing where the bottlenecks are.

While standardisation has been commonly applied to forensic methods [16, 17, 18, 19, 20], workflow analysis has been used only to a limited extent in the forensic field. A literature study conducted by the author previously showed that workflows were analysed, mainly to describe and standardise the forensic processes and give some suggestions regarding efficiency [21]. Workflow studies can be performed in different ways, such as observation, simulation, automation or data warehousing [22, 23, 24, 25]. However, the principle remains the same: a workflow is mapped out and analysed to determine improvement.

However, this method has been applied in the medical field: to reduce the high workload of medical professionals, the workflows of complex and extensive interventions in the medical field have been analysed and improved in terms of duration, using observational or simulation studies, also known as workflow analysis studies [26, 27]. The medical field is, to some extent, comparable to the forensic field. The workload is high, and because every patient is different – just like SVOs – it is difficult, if not impossible, to automate all

processes. The second similarity between the two fields is the high stakes. Due to the impact of their work, medical and forensic personnel bear a high level of responsibility. If mistakes happen, individual lives and society as a whole will be negatively affected. Considering the similarities with the forensic field, workflow analysis could be applied to the preliminary examination to improve the process in terms of time.

Therefore, a workflow analysis of the preliminary examination was performed at BiS to obtain the missing knowledge, analyse their workflow and find possible points of improvement to save time. The main research question of this study is: "What is the workflow of the preliminary examinations of SVOs for human biological traces at the NFI, and are there ways in which it could be improved to save time?". Additionally, this study analyses which SVO-related variables – such as the type of SVO or type of criminal case – influence the total duration of the preliminary examination, regardless of the workflow.

2. Background and scope

This study was conducted at the NFI and focused on the process of preliminary examination of human biological traces.

2.1. Process at the NFI of preliminary examination

2.1.1. SVO intake

The NFI offers a range of services to the Dutch criminal justice system. When a case is sent to the NFI, the Frontdesk, which manages SVO intakes, checks the request and transfers it to the correct division [28]. However, at times, the Frontdesk suspects that the requester overlooks certain types of SVO examinations. In these cases, they contact the requester and discuss additional examinations.

There are four main divisions at the NFI: Biological Traces, Digital and Biometric Traces, Chemical and Physical Traces, and Specialised Services and Expertise [29]. These divisions offer products, such as bloodstain pattern analysis (BPA) or gunshot residue analysis. Since these products are used to analyse their possible influence on the workflow, it is important to clarify the distinction between internal and external products. External products are known and available to external parties, such as the police. These external products often include the entire process of the examination of an SVO: from the preliminary examination of the SVO to the analysis of traces and the reporting of results. This is impractical for the NFI, so they also use internal codes that divide external products into smaller internal products. For example, HBS007 is the external product for a standard preliminary examination, including DNA analysis, and consists of at least the following internal product codes: BS_C007 (report) and BS_V007 (preliminary examination) [30].

Most external products at BiS have an internal product code that is specific to that external code. Exceptions to this are blood pattern analysis (BPA) and hair examination. BPA can also occur during examinations on cold and old cases, which belong to a different external product. Hair analysis can occur during all external codes except for HBS223, which is specific for BPA. Hair analysis rarely stands alone and is usually accompanied by another preliminary examination.

2.1.2. Examination of the SVO

Since this research focuses on human biological traces, the internal and external products of this division were further reviewed. From this point onward, external product codes will be used in this study because they are recognised outside the NFI as well. While these external product codes also include other parts of the examination, the focus of this study is on the preliminary examination part, specifically the detection, collection and securing of human biological traces.

The following external product codes are used at BiS and include preliminary examination of SVOs [31]:

- HBS007: DNA analysis with preliminary examination at the NFI.
- HBS206: DNA analysis and/or preliminary examination with urgency. SVOs with this product code are prioritised for examination earlier than those without urgency. Depending on the urgency, the SVO is examined on the same day as it is received.
- HBS208(A): DNA analysis and possible preliminary examination for the DNA of missing

persons.
- HBS209: Product intended for additional examination following prior examinations(s).
- HBS220: Preliminary examination and DNA analysis in old and cold cases.
- HBS223: BPA at the NFI on SVOs and/or based on the file.
- SPP201: Support and advice on the crime scene.

For most products, only one SVO can be submitted per product. Only for products HBS206 and HBS208, a maximum of three applies per agreement with external parties. For HBS206 (urgent), only three samples can be collected and secured to ensure they can be processed in a short time.

2.1.3. Trace analysis

Following the investigation of an SVO and the securing of traces, further examination and testing can take place. Preliminary examiners perform any serological tests, semen analysis and hair analysis themselves, while DNA analysis is performed by a different team within the division.

Serological tests are used to determine the presence of specific substances in a sample. RSID-saliva [32] is used to verify saliva, a prostate-specific antigen (PSA) test to detect the presence of semen, and RSID-blood [32] to prove there is blood on the SVOs.

In addition to the standard method of DNA profiling, three additional specialised options are available [33]:

- Differential lysis (DL): to separate semen from the rest of the biological material.
- Co-isolation (Co-iso): determine the organ where the trace originated from by RNA analysis.
- DL-Co-iso: combination of the two above – separate semen and determine RNA from the sample.

2.2. Evidentiary pieces and the complexity of their examination

2.2.1. Evidentiary pieces

The NFI receives a broad range of evidence: from cars to hard drives to sexual assault kits (SAKs). SVOs that can be processed with routine procedures often lack a research plan that contains the instructions for the examination made by the experts at the NFI. SVOs, such as SAKs and SVOs related to sexual assault cases, do have a research plan [34]; the same goes for most urgent cases, as the requester often needs to know something specific first as soon as possible, and the rest of the SVO can be examined later without the additional time pressure.

To avoid contamination, SVOs related to the victim and SVOs related to the suspect are examined in separate laboratories. SVOs related to crime scenes are placed in the laboratory that makes the most sense in terms of contamination and laboratory availability.

2.2.2. Levels of complexity

Depending on the complexity of the required examination, the NFI distinguishes four standard routes for securing and analysing trace evidence [34]: Route 1, Route 2 and Route 3.

- **Route 1 - Standard**: Least complex and most standard preliminary examination, as it includes tasks such as processing swabs or swabbing at predefined locations for wearer DNA.
- **Route 2 - Complex**: More complex and involves either interpretation of the case file or additional tests, such as RSIDs.
- **Route 3 - +BPA**: Involves BPA and is considered the most complex.
- **IVO-route - IVO**: Interdisciplinary examinations (“Interdisciplinair vooronderzoek”, IVO) in which different disciplines, such as fingerprints, fibres and textiles examination, are combined. The order of work within the IVO-route depends on the disciplines involved, as some examinations required by one discipline may be destructive to traces needed by another.

2.3. Types of preliminary examinations

2.3.1. BPA

BPA is part of BiS examinations and involves analysing the blood patterns on SVOs. Based on the location, shape, and distribution of the bloodstains, specific scenarios can be ruled out or constructed.

2.3.2. *Hair*

Hair can be collected from SVOs for hair analysis to determine the type of hair (head or pubic). Hair is secured on a 'hair card': a card with a sticky strip. Mitochondrial DNA is present throughout the hair shaft, while autosomal DNA is only found in the root. The hair roots contain a lot of DNA if they have been pulled from the body, and very little if the hair has fallen out naturally [35].

2.3.3. *Blood*

In addition to BPA, it can be important to know if and where blood is present on the SVO. This information can support or contradict a testimony. Furthermore, in cases where a victim has been stabbed, blood traces can be used to extract RNA to determine which organ was perforated, providing further insight into what transpired and potentially supporting or contradicting statements. Lastly, if the suspect's DNA is needed, it is crucial to avoid including the victim's blood in the same sample, as its high DNA content can overshadow the DNA of the suspect. SVOs can be examined under a microscope and white light to improve blood visibility, as well as under infrared light. To confirm whether a substance is blood, a Tetra Base (TB) test can be performed. Blood examination of an SVO is always reviewed by a second examiner to ensure that no traces are missed [36].

2.3.4. *Semen*

An SVO could be examined for semen in different ways. A Crime-lite, a handheld forensic light source, is often used to visually detect the presence of semen [37]. Blue light with a wavelength of 420-470 nm is used for this examination [38]. Bodily fluids like semen and saliva will light up, and these stains can be tested for semen using the presumptive acid phosphatase (ZF) test. Samples with presumed semen traces can be tested with a prostate-specific antigen test (PSA) to be sure the sample contains semen. They can be transferred to a cytospin, after which a microscope slide is made [39]. The sperm heads, if present, can be counted with the aid of a microscope. A ZF-print can also be made from an SVO: this happens on SVOs with a lot of traces that light up with the Crime-lite or the opposite as a last resort. This examination happens once or twice a year on average, sometimes in combination with an amylase-print. The SVO is placed between Phadebas paper, which reacts to saliva and turns blue, creating an amylase-print [40]. Subsequently, it can be treated with ZF to visualise semen stains, which turn purple; this is known as a ZF-print.

2.3.5. *Saliva*

While saliva can also be detected with the Crime-lite, it is less common. For confirmation of saliva, serological tests have to be performed. As mentioned before, while rare, an amylase print can be made from an SVO, mapping all the spots of saliva on Phadebas paper.

2.3.6. *Collecting traces*

An SVO can be swabbed with a cotton or nylon flocked swab if the surface is not porous, to collect traces. If the material of an SVO is porous, the trace is lifted using tape, also known as stubbing, to collect potential DNA. Stubbing is mostly used for SVOs made out of textile and paper materials. If the material is porous and the original trace was fluid (such as semen, blood or saliva), the trace can also be cut out to get the best results.

Some substances on the SVOs, such as soot and gunpowder, should be avoided during the collection of human biological traces, as they interfere with PCR if DNA analysis is needed.

2.4. *Statistics of preliminary examinations in the NFI*

2.4.1. *Type of cases*

To analyse which factors can influence the duration of the preliminary examination, it is useful to have an overview of the type of cases the NFI receives and their characteristics. An SVO is linked to a (criminal) case which is categorised by a type that is often assigned by the police, such as sexual assault or homicide. The main system where the case information is stored is called Promis [30]. Here, the cases, their details, and progress are recorded. A list of case types and their short description can be found in Table IX, Appendix A.

In some cases, a meeting is called to ensure everything is clear before the examination begins, or to update all parties involved. The latter happens

with complex cases and is referred to as forensic intake (FIT). For sexual offence cases and cases involving knives, a meeting is held by the Frontdesk with relevant experts from the NFI. These are often DNA and fingerprint specialists, but may also include an examiner from BiS. This measure was introduced after intake coordinators observed that such cases frequently led to follow-up questions from examiners, due to insufficient information for conducting a preliminary examination. The meeting allows the involved disciplines to discuss the case and clarify any outstanding questions.

Multiple SVOs can be linked to a case. When a new case is received, a case number is created, partly based on the date. For example, the case number 2024.10.03.001 consists of:

- 2024: the year the case was assigned to the NFI.
- 10: month of the year (October).
- 03: the day of the month.
- 001: first case registered on this date.

These four numbers create a case number. The request for an examination is added after the case number, creating a request number. First one receives 001 at the end of the case number: 2024.10.03.001.001. If another SVO or research question related to this case is submitted at a later time, the number at the end increases: 2024.10.03.001.002.

For the case type analysis in the current study, cases were categorised by crime type where possible. Cases without a specified case type are also included, though without the number of external products. An overview of the cases processed by BiS at the NFI in 2023 and their frequency of occurrence is shown in Table 1. The data was obtained from Promis on 8 October 2024 and extracted based on case numbers starting with the number 2023. The list includes all BiS cases, including those that did not require a preliminary examination at the NFI because it had already been performed by the police, with only DNA analysis remaining to be done [31].

In addition to the occurrence frequency of these types of cases, Table 1 also lists the median duration per case type, along with its interquartile range. This is calculated as follows: from the date of receiving the request until the case is finished at the NFI, which is when all activities in Promis have been completed. The starting date may differ from the case number date, as the starting date refers to when the request was received at the NFI, whereas the case number date is based on the date the case registration was completed in Promis. When the request is correct and complete, these two dates are the same. However, submission errors or missing information may require clarification, which results in a delay in case registration. Cases that, on the date of data extraction, were not finished yet were excluded from the calculation of the median. This overview of cases also excludes cases without a case type (145 occurrences in 2023).

Furthermore, the external products of preliminary examinations can be found in Table 1. This data was extracted from QlikView, a dashboard tool used at the NFI to monitor productivity and to filter and extract data. This data was obtained by filtering by year and the BiS division.

A slight discrepancy was found between the results for cases from Promis and from QlikView: a few cases that were included in Promis were filtered out as no division was assigned to these cases. The number of product codes may therefore be slightly higher.

2.5. *Scope*

Considering the preliminary examinations are conducted per SVO by BiS rather than per case, the focus of this study is the analysis on SVO-level examination. Although the same examiners often examine the SVOs from the same case consecutively, the workflow remains organised around individual SVOs.

The list of all SVOs received by the NFI was derived from the cases that were extracted for analysis of case types. However, there is little standardisation regarding the description of SVOs in Promis, and the entries vary. For example, underwear can be referred to as underwear, or with more detail, including the brand or type, such as boxer briefs. So, only an estimation was made of which SVOs were most common. Textiles (mainly clothing), human material (such as SAKs, swabs and nails), and weapons had the highest occurrence frequency.

TABLE I: Overview of cases with corresponding external product codes and their occurrence frequency. The median duration of the cases is also given in days. A brief description of each case type can be found in Table IX in Appendix A.

	Number of Cases	Median duration (Q1 - Q3) (days)	Occurrence frequency of external products codes that started in 2023						
			HBS007	HBS206	HBS208A	HBS209	HBS220	HBS223	SPP201
Private cases	15	118 (104 - 133)	4	0	0	11	0	0	0
Homicide, Assault, Deaths	431	70 (33 - 134)	252	140	108	307	0	14	5
DNA of convicted persons	16853	28 (23 - 36)	0	0	0	0	0	0	0
KLPD missing persons	51	55 (29 - 91)	2	1	51	0	0	0	0
Threats against personal freedom, violent	122	61 (36 - 125)	45	16	0	59	0	0	1
Sexual offences, Rape	476	66 (36 - 130)	346	81	0	453	0	0	0
Damage and Destruction	33	49 (29 - 89)	15	2	0	3	0	0	0
Other Destruction and Animal Cruelty	21	40 (25 - 73)	8	1	0	4	0	0	0
Arson, Explosions, etc.	317	108 (39 - 168)	107	58	9	107	1	0	0
Investigation of fireworks	8	57 (32 - 207)	4	0	0	5	0	0	0
Theft with and without violence	590	41 (25 - 88)	75	28	0	152	0	0	0
Burglary (HVC)	1528	20 (15 - 25)	0	3	0	20	0	0	0
Vehicle-related (HVC)	154	22 (17 - 28)	3	0	0	14	0	0	0
Other (HVC)	402	21 (16 - 29)	29	8	13	50	0	0	0
Serious Crime	97	21 (16 - 26)	4	4	0	9	0	0	0
Extortion, Fraud, Threats	10	70 (55 - 118)	6	0	0	9	0	0	0
Forgery and Counterfeiting	6	43 (33 - 165)	1	0	0	0	0	0	0
Other crimes under the Criminal Code	316	73 (28 - 174)	95	52	43	173	0	1	7
Terrorism	1	256 (256 - 256)	0	0	0	1	0	0	0
Road Trafic Act = Motor Vehicle Act	2	0	0	0	0	1	0	0	0
Death/Injury by negligence	3	173 (88 - 213)	2	0	0	0	0	0	0
Other road traffic crimes	4	204 (83 - 216)	0	0	0	0	0	0	0
Violation of the Opium Act	265	92 (50 - 147)	34	6	0	106	0	0	0
Weapons and Ammunition, Firearms	210	57 (39 - 113)	27	5	0	98	0	0	0
Miscellaneous, all other cases	252	66 (30 - 143)	61	21	30	78	1	2	3
IND-parentage investigation	624	16 (16 - 17)	0	0	0	0	0	0	0

3. Methods

3.1. Study design

An observation study was conducted of preliminary examinations of SVOs at BiS. The aim was to obtain a detailed workflow and analyse it to improve its time efficiency. The first step was to create a flowchart of the examiners' work process to identify actions that could be measured. The flowchart consists of the following components:

- **Actions**: individual activities performed by the examiners, such as collecting a trace with a swab.
- **Decisions**: points in the flowchart where the examiners choose how to proceed between different options depending on the circumstances.

- **Phases**: a group of actions (and optionally decisions) that together form a part of the SVO examination, such as collecting traces.

The workflow was analysed on three levels:

- **Entire workflow**: the workflow of the SVO examination from start to finish, and what influences the duration of the examination.
- **Phases**: which phases occur during an examination and their durations.
- **Actions**: which actions occur during an examination, and their durations.

By measuring the actions, the durations of phases and the entire examination were calculated to identify which parts of the workflow take the longest and to determine if they could be improved in terms of time efficiency.

Considering the sensitive nature of this forensic data, the collection of data for the workflow analysis needed to happen carefully. Thus, in this study, observation was used as a method for data collection to limit the risk of recording or exposing confidential information.

3.2. *Inclusion and exclusion criteria*

3.2.1. *External products and tasks of BiS*

Considering the wide variety of types of preliminary examinations, a selection of tasks performed by examiners at BiS was made to define a clear scope for this study. Based on section 2. and the data in Table 1, the preliminary examinations that are part of the following external codes were included:

- HBS007: DNA analysis with preliminary examination at the NFI.
- HBS206: DNA analysis and/or preliminary examination with urgency. These products get priority.
- HBS208(A): DNA analysis and possible preliminary examination of missing persons' DNA.
- HBS209: Product intended for additional examination following prior examinations(s).
- HBS220: Preliminary examination and DNA analysis in old and cold cases.

These external products were chosen because they have the highest occurrence frequency, which increases the chances of having sufficient data for analysis and enables making a bigger impact on optimising the workflow. Therefore, BPA and preliminary examination at the crime scene were excluded.

This workflow analysis focused on the preliminary examination of the SVO directly; therefore, serology, analysis of microscopic slides, and hair analysis, which were done after the extraction of traces obtained from the SVO, were excluded from the workflow process. Apart from BPA, examinations of SVOs with amylase and ZF prints were also excluded, as they are rare and were only observed once. No further examinations of SVOs were excluded.

Additionally, after data collection, it was decided to exclude multidisciplinary examinations in which multiple divisions worked simultaneously on the same SVO during the preliminary examinations. Only one such instance was observed – across several SVOs – and it involved just one additional division. This singular occurrence was insufficient for comparison with non-multidisciplinary workflows.

3.2.2. *Examinations rooms*

Examinations performed in spaces other than the BiS department laboratories are excluded to ensure consistency and comparability in the observed data, since they are stocked and organised differently. This excluded the preliminary examination at the NFI's explosives bunker and the fingerprints department, as well as preliminary examinations at the crime scene (SPP201).

3.2.3. *Evidentiary pieces*

As mentioned in Section 2., the SVOs with the highest occurrence frequency were: textiles, human material, and weapons and were the focus of this study. However, weapons are usually examined in a multidisciplinary setting in the fingerprints department or the bunker and are therefore rarely encountered in this observation study, because these spaces were excluded.

Nevertheless, due to the way SVOs were assigned and scheduled at BiS – SVOs were assigned to examiners without fixed time slots and often examined consecutively – other types of SVOs were also observed and included when they occurred in the same session as the focus SVOs.

3.3. *Workflow observations*

Preliminary examinations were observed three to four working days a week. This was sometimes extended to five days a week to fully observe preliminary examinations that were conducted over multiple days.

The number of examiners working on an SVO at a given time can vary. In some cases, a single examiner performs the entire process; in others, up to three people may be involved: one observing, one handling computer tasks, and one conducting the examination. The latter occurs only when an examiner is still in training. Due to this variation, and to ensure the quality of the observations, the decision was made to focus on the examination of the SVO. Thus, when one examiner was not directly working on the SVO, and one was, the focus was on the examiner working directly on the SVO.

The observations and measurements started in the sluice between the laboratories of BiS, where examiners put on personal protection equipment (PPE) before entering the DNA-free laboratory, and were finished when PPE was doffed after the examination, also called a lab session. In the sluice, supplies for the examinations are stored, as well as PPE, so it functions as both a gowning area and a storage space. The actions performed by the examiners were measured by registering the start and end times in Excel. The duration was calculated by subtracting the start time from the end time. At times, actions were followed so closely by the next that only the starting times could be registered. In those cases, the duration of an action was calculated by subtracting its starting time from that of the subsequent action. Per action, the following aspects were registered as well:

- SVO ID: to which SVO the action belonged.
- Lab session ID: to which lab session the action belonged.
- Notes: If any anomalies were observed, this was stated here.

The setup of an observation form can be found in Appendix B in Figure 8 and was based on the observation form used in the study by Loeve et al. in their workflow study on magnetic resonance-guided focused ultrasound surgery [27]. Additionally, data was also collected on SVOs per SVO ID, which includes anonymised researchers, details of the SVO, and the research question. This registration form can also be found in Appendix B in Figure 9.

The actions followed each other in quick succession, making it difficult to register the decisions. Therefore, the decisions were considered instantaneous with a duration of zero seconds and were added after the observation.

During the observation of a lab session, multiple SVOs could be examined, or the examination of a single SVO could be split across multiple sessions, as a full examination is not always completed within a single session. The latter occurs when a lab session is interrupted due to breaks or other time constraints. Therefore, the decision was made to analyse SVO examinations and lab sessions as two separate datasets. A distinction was made between actions and phases that involved direct physical interaction with the SVO and those that did not:

- **SVO phases**: Group of actions that required physical contact with the SVO or its traces until they were secured (put in cups for further analysis). Examples of SVO phases are: unpacking it or collecting traces from its surface.
- **Non-SVO phases**: Group of actions, such as cleaning the table after the examination or putting stickers on secured samples, which do not involve the SVO itself, were classified as non-SVO phases.
- **Flexible phases**: Group of actions that occurred throughout multiple phases, SVO and non-SVO phases, of the workflow. These included, for example, taking photographs during the examination to maintain the chain of custody, positioning the SVO, and putting on or removing additional gloves. Because these actions occurred throughout the workflow and not necessarily at fixed moments, they were grouped into flexible phases.

SVO examinations and lab sessions entail the following:

- **SVO examination**: includes only those actions and phases with direct physical involvement with the SVO and may span multiple lab sessions.
- **Lab session**: refers to the full observation period, including both SVO and non-SVO phases.

When an action belonged to a non-SVO phase, no SVO ID was registered.

3.4. Workflow description

To understand the detailed workflow of the preliminary examinations, a pilot was carried out to create a flowchart to map the actions during the examination. A pilot with 10 observation days without measurements included just over 30 SVO examinations, including multidisciplinary examinations, where examiners worked sequentially or simultaneously on an SVO in the same laboratory. The latter was later excluded due to the lack of observations. From the observed action paths, a flowchart was compiled with Microsoft® Visio® 2019 MSO (Version 2409) to visualise the work processes.

The observations were used to improve and optimise the initial flowchart created after the pilot. The last actions were added after SVO 45. Following this SVO, the existing flowchart and its actions were only optimised for the previous and subsequent SVO examinations. Phase 10a was especially optimised based on all the measurements. Due to the variety of SVOs and tailor-made examinations, the flowchart was optimised until the last observation.

The phases of the workflow that were identified during the pilot and observed, were labelled as either an SVO phase, a non-SVO phase, or a flexible phase. To explain the method of the study further, a short description of the phases is needed. These were the identified phases of the SVO examination at BiS:

- **Phase 1: SVO intake**
  Registration and transfer of the SVO to BiS.
- **Phase 2a: Entering the laboratory (non-SVO phase)**
  Putting on PPE and preparing for the SVO examination.
- **Phase 2b: SVO unpacking (SVO phase)**
  Opening and positioning the SVO for examination.
- **Phase 2c: Workflow interruptions and recovery in workflow (flexible phase)**
  Covering interruptions and recoveries that can happen during an examination.
- **Phase 3: Planning (SVO phase)**
  Determining how the examination is to take place.
- **Phase 4a – 4c: Trace detection (SVO phases)**
  Detecting hair, saliva, semen, or blood on SVOs, often with the help of technology.
- **Phases 5a – 5c: Collecting traces (SVO phases)**
  Optionally selecting the sample area and collecting traces for samples, either destructively or non-destructively
- **Phase 6a: Securing samples (SVO phase)**
  Putting the collected samples in a cup to secure the samples.
- **Phase 6b: Sample processing (non-SVO phase)**
  Preparing the previously secured samples for further analysis.
- **Phase 7: Sample kit preparation and handling (SVO phase)**
  Unpacking and processing of sample kits, such as SAKs.
- **Phase 8: Administrative tasks (non-SVO phase)**
  Accessing SVO-related information, reporting findings and processing the SVO and samples in Promis.
- **Phase 9: SVO finalisation (SVO phase)**
  Covering the SVO during or repackaging the SVO after examination.
- **Phases 10a – 10b: Wrap up (non-SVO phases)**
  Ending laboratory work and transferring secured samples to the appropriate location for further analysis.
- **Phases 11a – 11c: Supportive actions (flexible phases)**
  Changing of gloves, supporting action on the SVO, and managing materials.
- **Phase 12: SVO finish**
  Completing the examination of the SVO by finishing and checking the report.

An overview of the phases is provided in Figure 1.

BiS attempts to schedule SVO examinations in a manner that allows two examiners to work through this workflow to conduct the preliminary examination. One examiner focuses on administrative tasks (Phase 10), while the other examines the SVO (SVO phases). However, at the time this study took place, five new examiners were still being trained as part of a team of 10 people. Since not everyone was working every day and trainees cannot perform all examinations on their own, the examination was

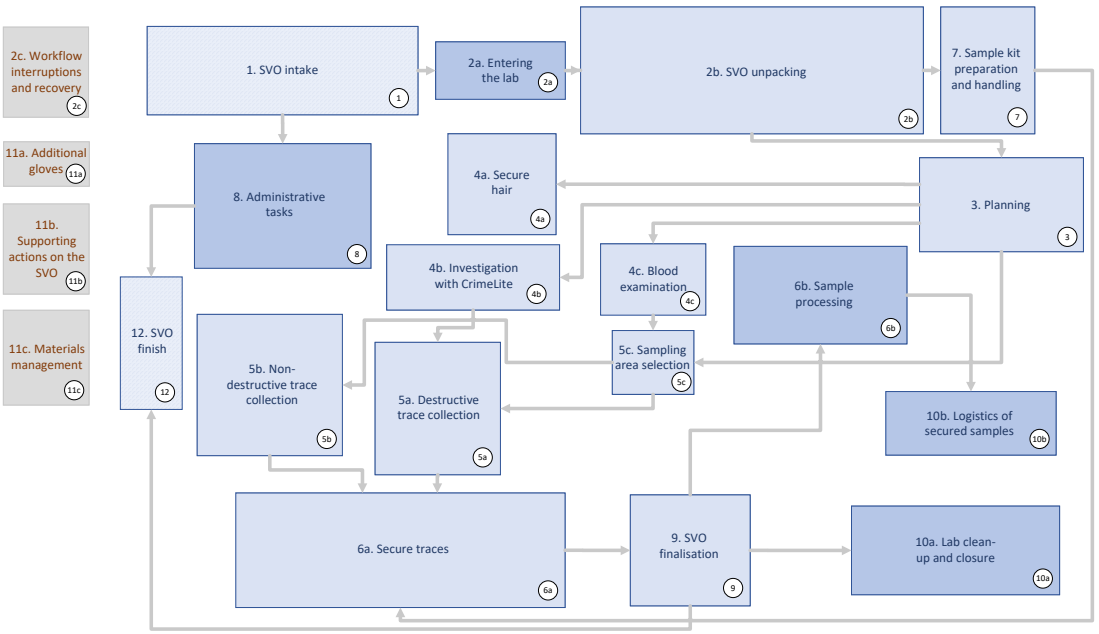

Fig. 1: SVO and non-SVO phases describing the workflow of the preliminary examination at BiS

often performed by three people, of whom two were trainees.

The detailed workflow begins when an SVO is registered at the NFI until it has been examined and the collected biological traces have been secured and are ready for analysis. For clarity, the data of a lab session can be divided into three categories:

- **SVO examination**: consists of SVO phases (Phase 2b until Phase 9) and associated actions of flexible phases (2c, 11a, 11b and 11c).
- **Non-SVO phases**: consists of non-SVO phases (Phase 2a, 6b, 10a, and 10b) and associated actions of flexible phases (2c, 11a, 11b and 11c).
- **Administrative tasks**: consists of the non-SVO phase 8.

Administrative tasks were difficult to observe simultaneously with the examination of the SVO. Thus, while the actions are described in the administrative tasks phase, only the phase was chosen to be measured, not the individual actions in this phase. Reporting, one of the administrative tasks, was also often started before and finished and checked after the examination outside the laboratory.

3.5. Sample size and ethical approval

Ethical approval for this study was obtained under ID: 4795 from the TU Delft Human Research Ethics Committee. Participants gave informed consent before data collection.

Lab sessions were included if they were fully observed: from entering until leaving the laboratory. SVO examinations were included if no more than the unpacking of the SVO (Phase 2b) was missed. Due to the way workdays are organised at BiS - without scheduled start times and a wide range of working hours (from 6:15 to 17:30) - observations started around 7 - 7:30 AM, which led to, at times, missing the beginning of early sessions. Additionally, SVO examinations were excluded if parts of the examination were missed, either due to lapses in attention or multiple SVOs being examined simultaneously, which made it difficult to observe all of them in full.

After the initial flowchart was made, the examinations of SVOs were observed and measured. A total of 58 SVO examinations were observed, and 45 were included for SVO examination analysis: 5 were excluded as they included simultaneous multidisciplinary examinations, and 4 were excluded

since too much was missed during observations to the extent that reconstruction based on comparable measurements or supporting documentation was not reliable, or the measurements were performed incorrectly. Lastly, 4 SVO examinations were excluded because more of the examination was missed than just unpacking the SVO. A total of 38 lab sessions were observed during the 45 included SVO examinations, and 34 were included for lab session analysis. 4 lab sessions did not include entering the laboratory, or a part of the lab session was not observed.

All 45 SVO examinations were used to analyse the duration of the preliminary examination. Out of 45 SVO examinations, 38 SVO examinations included the unpacking of the SVO, and seven did not. The set of 38 SVO examinations was used for the study of SVO phases and flexible phases. To investigate the influence of SVO-related variables such as the number of examiners and product code, the unpacking phase was removed from these 38 SVO examinations to create a larger dataset, allowing all 45 SVO examinations to be used. For the analysis of actions and decisions, two out of 45 SVO examinations were excluded as they were observed without always distinguishing which actions belonged to which SVO examination. Consequently, actions were registered together for both SVO examinations and not separately. Since the durations of these actions were divided over the two SVOs, this would be too inaccurate for the analysis of actions. Since the unpacking was also missed, the two SVO examinations are only included in the analysis of the duration of the examination and which SVO-related variables influence the total duration of the examination.

3.6. Data analysis

The collected data was processed in MATLAB® R2024b. As mentioned above, time was measured on different levels: actions and decision level, phase level, and SVO examination and lab session level.

3.6.1. SVO examinations

Per SVO examination, the durations with and without unpacking were determined to see how long an examination usually lasts:

- $\mathbf{t}_{\text{SVO-}}$: SVO examination duration with unpacking the SVO excluded (after Phase 2b up to and including Phase 9).
- $\mathbf{t}_{\text{SVO+}}$: SVO examination duration with unpacking the SVO included (from Phase 2b up to and including Phase 9).

Also, the average number of lab sessions ($\mathbf{n}_{\text{SVO/lab}}$) for an SVO examination was calculated: per SVO examination, the number of unique lab sessions was extracted, and the average number of unique lab sessions was calculated. This was calculated for SVO examinations with and without unpacking, and the two groups were tested for significance with the unpaired t-test. For this analysis, the excluded lab sessions were included for the calculation of ($\mathbf{n}_{\text{SVO/lab}}$). Even though the excluded lab session data was incomplete, only the lab session identification was needed for this analysis, since the observational data specific to lab sessions is not used in these calculations.

For the analysis of SVO phases, the following variables were calculated with the datasets of SVO examinations that included unpacking of the SVO:

- $\mathbf{t}_{\text{SVOphase}}$: The duration of an SVO phase, calculated from the first action (initiation) to the last action of that phase occurrence.
- $\mathbf{n}_{\text{SVOphase}}$: The total occurrence frequency, how often the SVO phase occurred over all SVO examinations with unpacking of the SVO.
- $\mathbf{n}_{\text{SVOphase/SVO}}$: The occurrence frequency per SVO examination, how often the SVO phase occurred during an SVO examination.
- $\mathbf{p}_{\text{SVOphase/SVO}}$: The percentage of each phase's total duration relative to the total SVO examination duration.
- $\mathbf{p}_{\text{act/SVOphase}}$: The percentage of time spent per SVO phase occurrence on phase actions relative to the phase occurrence duration.
- $\mathbf{p}_{\text{flex/SVOphase}}$: The percentage of time spent per SVO phase occurrence on flexible phases' actions relative to the phase occurrence duration.

An SVO phase occurrence was defined as at least two consecutive actions and/or decisions related to the same phase, following at least two actions or decisions from a different phase, except for flexible phases. Recurring occurrences of the same phase were identified when the previous occurrence was interrupted by at least two consecutive actions and/or decisions of another phase, and followed by

two or more consecutive actions and/or decisions of the original phase. $\mathbf{t}_{\text{SVOphase}}$ was tested with the Lilliefors test for normal distribution.

The duration of each action within the SVO phases was measured ($\mathbf{t}_{\text{SVOact}}$), and on the action and decision level, the following variables were calculated:

- $\mathbf{n}_{\text{SVOstep}}$: Total occurrence frequency over all SVO examinations.
- $\mathbf{n}_{\text{SVOstep/SVO}}$: Per SVO examination occurrence frequency, calculated for SVO examinations where the corresponding phase was present.

Since the decisions are noted with the duration of zero seconds, only $\mathbf{n}_{\text{SVOstep}}$ and $\mathbf{n}_{\text{SVOstep/SVO}}$ are calculated for decisions.

3.6.2. Lab sessions

The duration of a lab session ($\mathbf{t}_{\text{lab}}$) was measured from putting on Personal Protection Equipment (PPE) in the sluice (Phase 2a or 2c) up to and including removing PPE (Phase 10a or 2c). The average number of SVO examinations ($\mathbf{n}_{\text{lab/SVO}}$) for a lab session was calculated: per lab session examination, the number of unique SVO examinations was extracted, and the average number of unique SVO examinations was calculated. For this analysis, the excluded SVO examinations were included for the calculation of ($\mathbf{n}_{\text{lab/SVO}}$). Similar to SVO examinations, an SVO ID was sufficient for this analysis; therefore, the excluded SVO examinations were also taken into account.

As mentioned before, lab sessions consist of three parts, resulting in the following variables for analysis to investigate on what most time was spent during a lab session:

- $\mathbf{t}_{\text{lab\_SVO}}$: Time per lab session spent on SVO examinations.
- $\mathbf{t}_{\text{lab\_admin}}$: Time per lab session spent on administrative tasks.
- $\mathbf{t}_{\text{lab\_lab}}$: Time per lab session spent on non-SVO phases.
- $\mathbf{p}_{\text{lab\_SVO}}$: Percentage of time spent on SVO examinations per lab session.
- $\mathbf{p}_{\text{lab\_admin}}$: Percentage of time spent on administrative tasks per lab session.
- $\mathbf{p}_{\text{lab\_lab}}$: Percentage of time spent on non-SVO phases per lab session.

Further analysis of lab sessions was comparable to those of SVO examinations, resulting in the following variables for non-SVO phases:

- $\mathbf{t}_{\text{labphase}}$: The duration of a non-SVO phase, calculated from the first action (initiation) to the last action of that phase occurrence.
- $\mathbf{n}_{\text{labphase}}$: The total occurrence frequency, how often the non-SVO phase occurred over all lab sessions.
- $\mathbf{n}_{\text{labphase/lab}}$: The occurrence frequency per lab session, how often the non-SVO phase occurred during a lab session.
- $\mathbf{p}_{\text{labphase/lab}}$: The percentage of each phase's total duration relative to the total lab session duration. $\mathbf{p}_{\text{act/labphase}}$: The percentage of time spent per non-SVO phase occurrence on phase actions relative to the phase occurrence duration.
- $\mathbf{p}_{\text{flex/labphase}}$: The percentage of time spent per non-SVO phase occurrence on flexible phases' actions relative to the phase occurrence duration.

Although administrative tasks (Phase 8) are also a non-SVO phase, this phase is analysed differently since it is measured as a phase rather than on an action level and often occurs during the other SVO and non-SVO phases.

The occurrences of non-SVO phases were determined differently than for SVO phases. SVO phases were sequential, with each phase beginning after the previous one was completed. In contrast, Phases 6b, 10a, and 10b may occur simultaneously during a lab session. To distinguish separate occurrences of these phases, a time-based threshold was established, considering that non-SVO phases occur before and after SVO examination, and rarely during. Based on the observation data, there was at least 11 minutes between the start times of actions belonging to the same phase, and there was always less than 11 minutes between decisions or actions of the same phase occurrence. Thus, if the threshold of 11 minutes was reached, they were considered separate occurrences. $\mathbf{t}_{\text{labphase}}$ was also tested with the Lilliefors test for normal distribution.

Same as for SVO phases, each action of the non-SVO phases in a lab session was measured and resulted in the following variables:

- $\mathbf{t}_{\text{labact}}$: Duration of an action of a non-SVO phase.

- $\mathbf{n}_{\text{labstep}}$: Total occurrence frequency of actions or decisions over all lab sessions.
- $\mathbf{n}_{\text{labstep/lab}}$: Per lab session occurrence frequency, calculated for lab sessions where the corresponding phase was present.

3.6.3. Flexible phases

Flexible phases occurred frequently and, therefore, to determine their total contribution to $\mathbf{t}_{\text{SVO+}}$ and $\mathbf{t}_{\text{lab}}$, they were looked at separately as well. For the analysis of lab sessions, the SVO examinations were excluded to see how flexible phases impacted SVO and non-SVO phases. The following variables were calculated for both datasets (SVO examinations and lab sessions):

- $\mathbf{t}_{\text{flex}}$: The duration of the flexible phases was calculated by summing all durations of the phases' actions per SVO examination or lab session.
- $\mathbf{n}_{\text{flex/data}}$: Occurrence frequency of the actions per flexible phase per SVO examination or lab session, determined by counting all the actions corresponding to a flexible phase per SVO examination or lab session.
- $\mathbf{p}_{\text{flex/data}}$: The percentage of time spent on flexible phases per SVO examination (with unpacking) or lab session relative to their durations.

Datasets without the flexible phase were excluded from this analysis.

Per action of the flexible phases, the following variables were calculated:

- $\mathbf{t}_{\text{flexstep}}$: Duration of an action of a flexible phase.
- $\mathbf{n}_{\text{flexstep}}$: Total occurrence frequency per action across all SVO examinations and lab sessions.
- $\mathbf{n}_{\text{flexstep/alldata}}$: Total occurrence frequency per action across all SVO examinations (with unpacking) or lab sessions.
- $\mathbf{n}_{\text{flexstep/data}}$: Occurrence frequency of the action per lab session or SVO examination.
- $\mathbf{t}_{\text{flexstep/data}}$: Durations of the action of all occurrences per lab session or SVO examination combined.

At the start of observations, 11c X1 and 11c X2 were one action. This oversight was discovered after some observations and subsequently corrected: a distinction was made between collecting materials from the laboratory (11c X1) and the sluice (11c X2). This, however, meant that for a subset of observations, the location from where the materials were collected was unspecified. To take this into account as part of the flexible phase 11c: Materials management, and for the sake of analysis, this step was called 11c X0

3.6.4. Influence of SVO-related variables

To analyse the influence of SVO-related variables on the duration of the examination of the SVO, the data collected on SVOs was used (registered in the registration form in Appendix B, Figure 9). The following grouping variables were identified and analysed by performing the Kruskal-Wallis test on $\mathbf{t}_{\text{SVO-}}$ of all 45 SVO examinations:

- **Category of SVO**: Category in which the SVO is placed, such as clothing.
- **Material of SVO**: The main material that the SVO consists of, such as textiles. When the SVO consisted of multiple materials and the main material could not be identified, it was categorised as mixed.
- **Case type**: The type of case where the SVO comes from, for example, homicide.
- **External Product Code**: The way the preliminary examination is noted in the administration for external purposes.
- **Internal Product Code**: The way the preliminary examination is noted in the administration for internal purposes.
- **Levels of complexity**: Whether the SVO examination is labelled as Standard, Complex or IVO.
- **Research question**: The research question from the corresponding case file of the SVO is categorised on which human biological trace needed to be examined.
- **Number of researchers**: the number of researchers who worked on the SVO.

3.7. Supplemantary questionniare

Observational studies reveal the most time-consuming activities. However, examiners at BiS are familiar with the current workflow and can provide information beyond time-based bottlenecks. To get their opinions on the current workflow, its problems and possible solutions, they completed

a questionnaire. The questionnaire questions are listed in Appendix C. The questionnaire was filled in on paper, and the answers were summarised by the author per question.

3.8. *Optimising the workflow*

The obtained detailed workflow, analysed data, and the results of the supplementary questionnaire were combined to identify which processes might currently take longer than necessary. Phases or actions with a relatively long median duration were examined to identify where improvements could be made to reduce the time needed per occurrence. Bottlenecks were identified based on data from observations and the examiners' experiences, as reported in the supplementary questionnaire. To better understand them, these bottlenecks were examined with the help of observations, data analysis, and questionnaire results. The identified bottlenecks needed different approaches:

- Comparing durations for specific actions in both SVO examinations and lab sessions, and testing their durations with an unpaired t-test.
- Comparing the first occurrence of a phase with its recurrences as well as analysing the composition of that phase.
- Analysing the responses in the questionnaire.
- Analysing the responses in the questionnaire in combination with the duration of the corresponding actions.
- Analysing the responses in the questionnaire in combination with the duration of the phase and its actions.
- Analysing the responses in the questionnaire in combination with the data on the organisation of lab sessions.

4. Results

4.1. *Observations*

An overview of the 45 included SVO examinations is presented in Appendix D, Table X. In this overview, the characteristics of each SVO are also listed, including the category to which the SVO belongs, as well as which SVO examinations were observed in full (including the unpacking of the SVO).

4.2. *SVO examinations and lab sessions*

As the preliminary examination on the SVO is separated from the lab sessions, the durations of both were analysed. In Figure 2, a scattered boxplot depicts $\mathbf{t}_{lab}$, $\mathbf{t}_{SVO+}$, and $\mathbf{t}_{SVO-}$. All of the 34 lab sessions were used. As for the SVO examinations, SVO examinations with unpacking included 38 SVO examinations, and SVO examinations without unpacking included all of the 45 SVO examinations.

$\mathbf{n}_{lab/SVO}$ was 1.8, with at least 1 and a maximum of 6 SVO examinations per lab session. $\mathbf{n}_{SVO/lab}$ was 1.3 for SVO examinations with unpacking and $\mathbf{n}_{SVO/lab}$ for SVO examinations without unpacking it was 1.4 (7 SVO examinations), but the unpaired t-test proved this to be insignificant. The combined dataset of SVO examinations had a $\mathbf{n}_{SVO/lab}$ was 1.4. The minimum observed lab sessions per SVO examination was 1, and the maximum was 5.

The durations and contribution of the components of lab sessions (SVO phases, non-SVO phases and Administrative tasks) can be found in Table II.

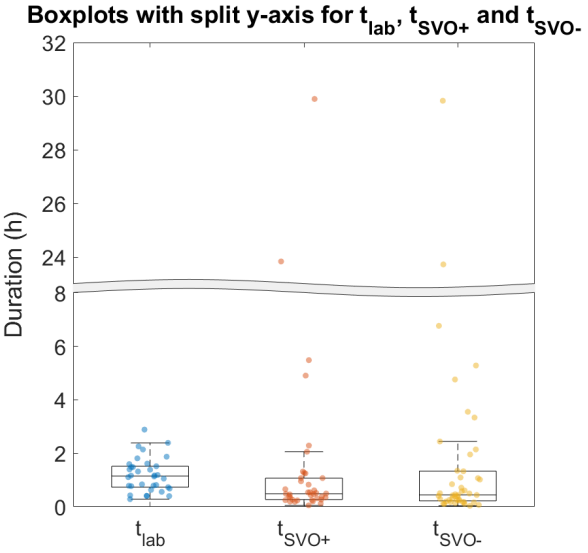

Fig. 2: $\mathbf{t}_{lab}$, $\mathbf{t}_{SVO+}$, $\mathbf{t}_{SVO-}$ depicted in scattered boxplots. The y-axis was split as the outliers were not finished on the same day. Lab sessions included 34 observations, SVO examinations with unpacking, 38, and SVO examinations without unpacking, 45 observations.

TABLE II: Lab sessions divided into three categories with the duration in minutes.

Component	Median duration (Q1 – Q3) (mm:ss)	Mean ± SD of percentage per lab session
SVO examination	48 (33 – 76)	81 ± 33 %
Administrative tasks	31 (21 – 63)	58 ± 30 %
Non-SVO phases	12 (8 – 17)	20 ± 12 %

TABLE III: *p*-values from the Kruskal-Wallis test on $\mathbf{t}_{\text{SVO-}}$ for each SVO-related variable. Full test details can be found in Appendix E in Table 6. A *p*-value below 0.05 is considered statistically significant and is marked with *.

Factor	*p*-value
Category SVO	.008*
Material SVO	.065
Case Type	.080
External Product Code	.061
Internal Product Code	.061
Level of Complexity	< .001*
Research Question	.004*
Number of Researchers	.436

Influence of SVO-related variables on $\mathbf{t}_{\text{SVO-}}$ was analysed. Per SVO, the category for each variable can be found in Appendix D in Table X. The test results per factor are presented in Table III, and a detailed table with the categories is provided in Appendix E, Table 6. A significant effect on $\mathbf{t}_{\text{SVO-}}$ of the following SVO-related variables was found: Category SVO, Levels of Complexity, and Research Question.

4.3. Detailed workflow

The workflow and its phases were introduced in Section 3. The workflow is further explained here, and a detailed workflow is presented at the end of this report in Figure 3, accompanied by a legend that explains the symbols used. The workflow of the preliminary examination of SVOs is walked through with the help of its phases:

Figure 3 is included in A1 format at the end of this thesis.
A reduced version is not shown here due to size constraints.

Fig. 3: Detailed workflow of the preliminary examination of SVOs at BiS, including a legend.

- **Phase 1: SVO intake**
  A request for a preliminary examination is submitted, and the corresponding SVO(s) are sent to the NFI. The Frontdesk registers the case, case file, and SVOs in Promis. They also organise a meeting to discuss the preliminary examination if necessary. When the intake is completed, the SVO is transferred to the sluice of the right laboratory at BiS, where it can be collected for examination.
- **Phase 2a: Entering the laboratory (non-SVO phase)**
  Several preparations are necessary before the laboratory process can start. In the sluice, the researchers put on the required PPE: face masks, hairnets, lab coats, and gloves. Here, the SVO and clean tools are also collected for the SVO examination. When the PPE are donned and the correct SVO is collected, the DNA-free laboratory is entered. Before the SVO can be examined, the table on which the examination will take place is cleaned.
- **Phase 2b: SVO unpacking (SVO phase)**
  The SVO can now be placed on the table for unpacking and opened. When the contents of the SVO are swabs, the examination is continued in Phase 7. Other SVOs are removed from the package and placed on an examination sheet. The package is usually removed from the table, and that part of the table is cleaned. If the SVO is frozen, it first needs to thaw, and if the SVO is wet, it is placed in the fume hood to dry. Examiners can wait for this process or continue to Phase 10a. If there are no SVO anomalies, the SVO is positioned for examination and optionally further inspected and described in detail (e.g., sweater size). An additional examination sheet can be placed to make the positioning of the SVO easier.
- **7: Sample kit preparation and handling (SVO phase)**
  When the SVO is a swab or a kit of swabs,

the unpacking and processing differ from those of other SVOs. The items in the package are placed on an examination sheet and photographed. If some of the items do not need to be processed, they are put back in the package. Per sample, the swab is taken out of the tube and checked for hair. If a hair is found, it is collected on a hair card. The sample can then be secured in Phase 6a.

- **Phase 3: Planning (SVO phase)**
  After unpacking the SVO, often a plan for examination needs to be made. However, determining the right approach for the continuation of the SVO examination can happen after every SVO phase. When help from outside the laboratory is deemed unnecessary, the plan for examination is determined, and the SVO is positioned accordingly. Once a plan is successfully made, the examination can continue. If help is needed to create a plan, the help (expert or other examiner) is contacted. The examiners can now choose to wait for the help and create a plan together, or continue the examination if possible. If continuation of the examination is not possible, the workflow is continued in Phase 9.
- **Phase 4a: Collection of hair (SVO phase)**
  After unpacking, the SVO can be examined for hair fragments. A hair card to collect hairs is taken, and the SVO is looked at with the white light of the microscope. The found hairs are put on the hair card. This process is repeated if another side of the SVO needs to be examined.
- **4b: Examination with Crime-lite (SVO phase)**
  A Crime-lite is usually used to examine an SVO for the presence of saliva or semen. The laboratory is darkened in preparation, and protective yellow glasses are put on. Additionally, the AP solution sometimes still needs to be mixed. After the preparations are completed, the SVO is inspected and visually scanned with the Crime-lite and traces found are marked with a marker. When this action is completed, the lights are turned on again, and the Crime-lite is put away. If the examination is for semen traces, the marked traces are tested for semen with the AP solution. The findings of the testing are discussed, often during the testing, before testing is continued.
- **4c: Blood examination (SVO phase)**
  The SVO is examined to find blood traces. Presumed blood stains are TB tested immediately, but the SVO can also be visually inspected for possible blood traces, optionally with the help of a microscope and/or its white light. When blood traces are hard to find with the naked eye and microscope, an infrared camera is used to try to detect them.
- **5c: Sampling area selection (SVO phase)**
  Before a trace is collected from an SVO, examiners may need to ensure whether the sample area contains blood traces or not. The area can also be TB tested.
- **5a: Destructive trace collection (SVO phase)**
  When traces are found or suspected on a porous SVO, they can be destructively collected by cutting them out with either scissors or a scalpel. This mainly concerns liquid traces such as blood, semen or saliva. However, when a different side of the SVO can be contaminated by another trace, that side needs to be cleaned with bleach and rinsed with water before it can be cut. Another possibility is that the trace is not on the outer layer of an SVO, thus needing the removal of a layer before the trace can be reached for collection.
  If the trace is not cut out entirely, the cut trace is put in a cup before continuing the collection of the trace. To ensure the entire blood trace is collected, the sample area can be TB tested. If the cutout trace is too big to put in a cup, it is cut into smaller pieces. These traces are secured as samples in Phase 6a.
- **5b: Non-destructive trace collection (SVO phase)**
  Traces can also be collected non-destructively with either a stub (tape-lifting) or a swab. These traces are often contact DNA traces or traces on non-porous SVOs. Stubs are typically used for porous materials, such as clothing and other textiles. Swabbing is usually done with a wet swab to help lift and absorb traces, except when the SVO is already wet [41]. For complex surfaces (e.g., wood) and shell casings, wetted nylon flocked swabs can also be used. If the surface of an SVO is swabbed, hairs can also be collected, which are collected in a hair

card. After the traces are collected and samples are created, it may be unnecessary to analyse all the collected samples. Therefore, for some samples, it is decided not to analyse the trace right away.

- **6a: Securing samples (SVO phase)**
  After a sample is collected, it can be TB tested. Depending on the type of trace, either the tape is removed from the stub or the tip of a swab is detached. In rare cases, when swabs are on a wooden stick, the tip material needs to be removed from the stick if the samples are to be analysed with serological tests. At times, pieces of SVO are so small that they do not need to be collected from the SVO and can simply be placed in the cup, such as a small part of a nail.
  Then, the choice is made regarding which cup the trace is put in for further analysis. If the sample was TB positive, it is placed on a green square to be photographed. If a sample tests negative, it is placed on a red square; if the trace is not tested, it is put on a white square. Sometimes traces can be combined in one cup to increase the odds of finding a DNA profile. When all the traces are collected in the cup, the cup is placed in a cup holder.
- **9: SVO finalisation (SVO phase)**
  When the examination of an SVO is interrupted, the SVO is covered with a protective sheet. The package is thrown away if all the samples inside have been processed. If a finished SVO is not used up, it is put back in the package with the examination sheet. If the SVO has not yet been opened at the NFI, the department name and date of examination are written on the package. Additionally, a yellow sticker is put on sample kits. After concluding an SVO examination, the workflow is continued in Phases 10a and 6b.
- **6b: Sample processing (non-SVO phase)**
  After the samples are secured in cups, they are processed in preparation for analysis. If the sample is not to be tested for serology or RNA, ATL buffer [42] is added to the cup. If it is a rushed case or the samples need to be tested for serology or RNA, the traces are placed in cups without barcodes and require stickers for identification and administration. After processing, the cups are placed in a container with a label.
  After hair is collected in a hair card, tracking stickers (SIN) are placed on the card for identification. The case number and origin are written on the card before placing it in an envelope with the SIN sticker and an NFI seal. The workflow for both processed samples continues in Phase 10b.
- **10b: Logistics of secured samples (non-SVO phase)**
  Hair cards are brought to the sluice. Cups that do not require serology testing are placed in the refrigerator in the sluice. Cups that require serology testing are brought to the serology laboratory.
- **10a: Laboratory clean-up and closure (non-SVO phase)**
  After finishing an examination, it can be decided to leave the laboratory. In both cases, the SVO is removed from the table if the examination is concluded and the table is cleaned. The examined SVO is brought back to the sluice. If it is decided to continue working in this lab, the workflow continues in Phase 2b if a new SVO examination is started, and 2c if an SVO examination is continued. When the examiners decide to leave the laboratory, they clean and close it (e.g. turning off the devices and lights) if they do not return that day. They can optionally clean the lab before leaving if they continue working in this lab that day. Before the examiners leave the laboratory, they remove their PPE.
- **8: Administrative tasks (non-SVO phase)**
  This phase can start before the examiners go to the laboratory. In these cases, the observation form corresponding to the case is created on a computer, which may need to be started up. An observation form can also be made before the SVO examination in the laboratory. Photos are uploaded from the SD card, and sampled areas are marked. Traces are registered in Promis, and the observation form is completed. The latter can also happen outside the laboratory. The workflow continues to Phase 12.
- **12: SVO finish**
  The SVO's examination has been completed, and the examiners have written and checked

the report. Thus, the preliminary examination of an SVO is completed.

- **11a: Additional gloves (flexible phase)**
  When there is (possible) contact with the evidential piece or its traces, additional glove changes are needed prior to the contact to minimise the risk of contamination.
- **11b: Supporting actions on the SVO (flexible phase)**
  This flexible phase covers actions that are necessary, but are not necessarily part of the examination of the SVO, such as taking photos, positioning and cutting open the SVO.
- **11c: Materials management (flexible phase)**
  This flexible phase has actions related to the materials needed to make the examination possible. Examples are: getting materials from the sluice and cleaning tools.
- **2c: Workflow interruptions and recovery (flexible phase)**
  This phase occurs when the examiners leave the laboratory or continue an examination that has already begun, but it is also used when a mistake takes time to correct.

4.4. Analysis of SVO and non-SVO phases

$\mathbf{t}_{\text{SVOphase}}$ and $\mathbf{t}_{\text{labphase}}$ are presented in terms of medians and interquartile ranges to take outliers less into account. Furthermore, only half of the durations of the non-SVO phases and 3 out of 10 SVO phases were normally distributed (Phase 4b, 5a, 5c, 10a and 10b). In Figure 4, a scattered boxplot of each phase occurrence is shown for each phase. On the right-hand side of the figure, the following data is depicted:

- The average $\mathbf{p}_{\text{SVOphase/SVO}}$ or $\mathbf{p}_{\text{labphase/lab}}$ and their standard deviations.
- The average $\mathbf{p}_{\text{act/SVOphase}}$ or $\mathbf{p}_{\text{act/labphase}}$ and their standard deviations.
- The $\mathbf{p}_{\text{flex/SVOphase}}$ or $\mathbf{p}_{\text{flex/labphase}}$ and standard deviations.
- The average $\mathbf{n}_{\text{SVOphase/SVO}}$ or $\mathbf{n}_{\text{labphase/lab}}$ and standard deviations.

Phase 4b: Examination with Crime-lite and Phase 4c: Blood examination have the longest median $\mathbf{t}_{\text{SVOphase}}$, respectively 28:44 and 12:26 minutes and seconds.

In Table V, the analysis of flexible phases is given for both SVO examinations and the lab sessions. The flexible phases mostly occur during the SVO examination. The table of the actions of flexible phases is found in Table XVI, Appendix G.

Tables of all collected observation data for each action and decision, organised by phase, can be found in Appendix F. The ten actions with the longest ($\mathbf{t}_{\text{SVOact}}$) are stated in Table IV. For each action, the median $\mathbf{t}_{\text{SVOact}}$ is stated with its interquartile range, $\mathbf{n}_{\text{SVOstep}}$ and the average $\mathbf{n}_{\text{SVOstep/SVO}}$.

4.5. Examiners on the workflow

Nine BiS examiners completed the questionnaire. Four respondents had over 10 years of experience with the preliminary examination, two had between one and five years of experience, and three had less than one year of experience. Responses to the questionnaire are summarised per question in Appendix H. Responses that were given more than once are summarised in Table VI.

Complex SVO examinations were seen as labour-intensive, especially examinations with Crime-lite of semen and blood examinations (respectively mentioned by 4 and 5 respondents). Additionally, Crime-lite was one of the devices that respondents would like to see improved in terms of battery life, better imaging and ease of use. Other faulty devices mentioned were label printers, computers, and single-lens reflex cameras. Interestingly, the tasks experienced as most labour-intensive were also the phases with the longest durations (Phases 4b and 4c).

The most mentioned part of the preliminary examination in the questionnaire was the administrative tasks. Aspects of the administrative tasks that were seen as most problematic were the repetitiveness, lack of automation, and editing of photos with Photoshop (respectively, 2, 3, and 3 respondents).

Specific suggestions that were mentioned once included: automating adding ATL buffer to cups with samples, logging in with work ID cards instead of authentification by mobile phone to avoid contamination and delegating serological tests to other teams. Lastly, the suggestion was made to acquire a microscope with screen-sharing capabilities.

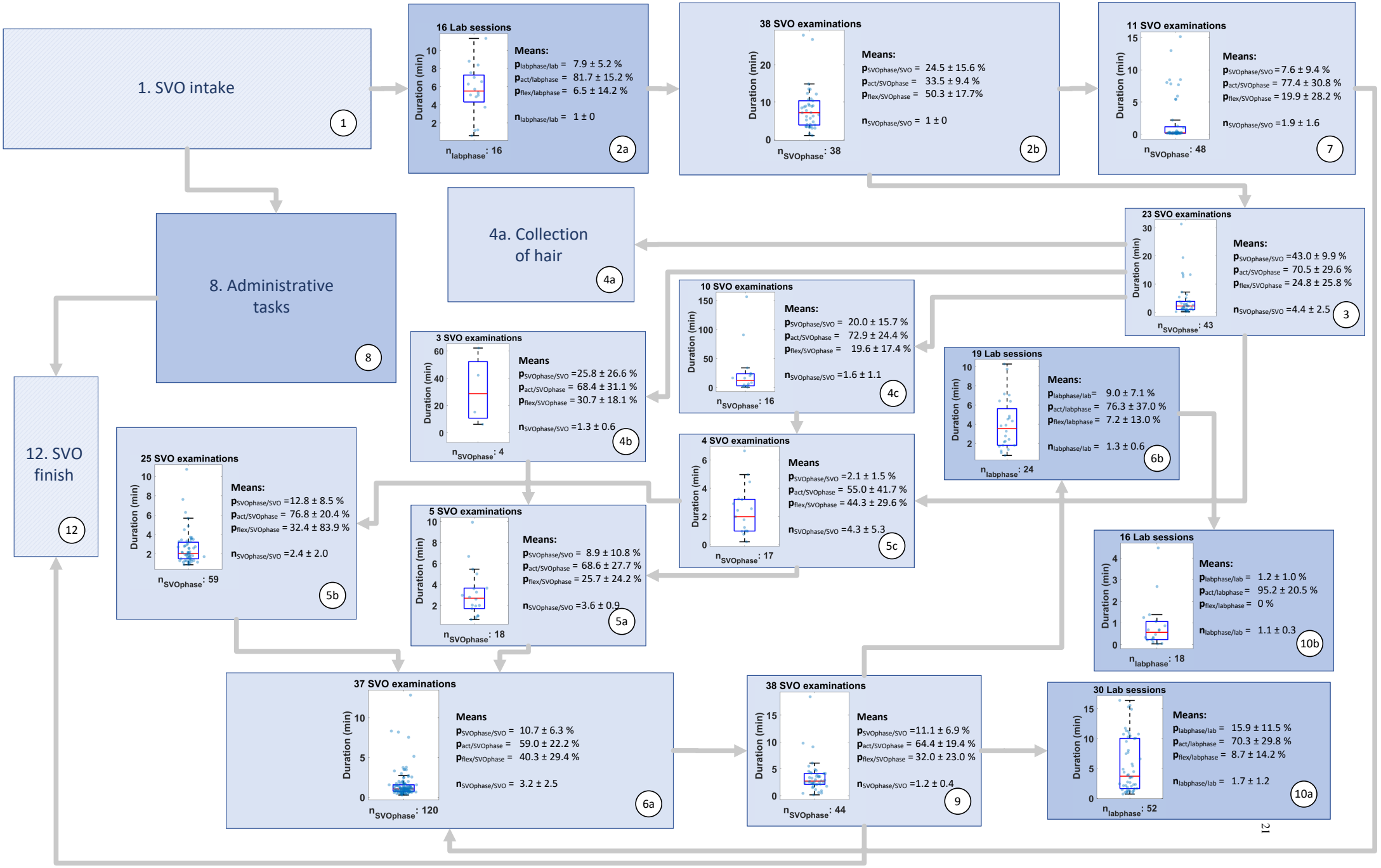

Fig. 4: Median duration ($\mathbf{t}_{\text{SVOphase}}$ and $\mathbf{t}_{\text{labphase}}$) and interquartile range per phase, visualised with scattered boxplots. On top of the boxplot is stated in how many SVO examinations the phase occurred, and below $\mathbf{n}_{\text{SVOphase}}$ or $\mathbf{n}_{\text{labphase}}$. The right side either shows the average $\mathbf{p}_{\text{SVOphase/SVO}}$, $\mathbf{p}_{\text{act/SVOphase}}$, $\mathbf{p}_{\text{flex/SVOphase}}$, and $\mathbf{n}_{\text{SVOphase/SVO}}$ for SVO phases or $\mathbf{p}_{\text{labphase/lab}}$, $\mathbf{p}_{\text{act/labphase}}$, $\mathbf{p}_{\text{flex/labphase}}$, and $\mathbf{n}_{\text{labphase/lab}}$ for non-SVO phases, all with standard deviations.

4.6. Observed measures improving the efficiency

During observations, multiple measures were observed during the preliminary examination that were currently benefiting the process in terms of time and should be maintained. The measure with the highest impact is how SVOs are assigned to examiners by BiS's planning. By assigning the SVO examinations belonging to a single case to the same examiners, the case file does not need to be reviewed by additional examiners. Furthermore, the planning assigns examinations in such a way that multiple SVOs can be examined in the same laboratory by the same examiners — this avoids closing the laboratory, doffing PPE, and then donning PPE again in a different sluice and starting up that laboratory (Phase 10a and Phase 2a).

Another measure is the division of tasks during an examination. As mentioned before, ideally, an examination is performed by two people: one examiner handles the administrative tasks, while the other examines the SVO. However, at the moment, an experienced examiner is often joined by two trainees. Although three people are not ideal for the preliminary examination, examiners try to be helpful. Apart from the examiner handling administrative tasks and the examiner who focuses on the examination, the third can photograph the process to reduce the number of times additional gloves are put on and taken off.

SVOs are currently examined simultaneously when they belong to the same case and can be examined in the same laboratory when this is more time-efficient. This is the case if an expert needs to take a look at the SVOs as well, or if an examiner from a different division needs to examine the SVOs too; this avoids contacting and waiting for other people twice. Another example of when examining SVOs simultaneously is more time-efficient is during blood examinations (Phase 4c). Since blood examinations always need to be checked by another examiner, examiners switch SVOs for checking once they have completed their initial blood examination.

4.7. Short-term solvable bottlenecks

4.7.1. Better material management

Considering the results of the questionnaire and Table V, the flexible phase 11c was further analysed. Insufficient stockage of supplies affects Actions 11c X1 (Collect materials from the lab), 11c X2 (Collect materials from the sluice), and 11c X0 (Not reported where materials where collected from). If the lab is insufficiently stocked with supplies, the examiners have to get their materials from the sluice. The workflow is interrupted because the laboratory needs to be left, and the risks of contamination increase, considering the sluice is not DNA-free. The boxplot in Figure 6 shows that, generally, it takes longer to collect materials from the sluice, with larger outliers, compared to collecting materials from the lab. An unpaired t-test confirmed a significant difference in the $\mathbf{t}_{\text{flexstep}}$ of 11c X1 and 11c X2 ($p < 0.001$). There were also instances observed, where first the laboratory was checked for a material (11c X1), which was not found, so it was collected from the sluice. The big outliers in 11c X2 were from a period when their BiS almost ran out of stubs, so multiple sluices were checked.

To map the influence suboptimal materials management has on $\mathbf{t}_{\text{lab}}$ and $\mathbf{t}_{\text{SVO+}}$, the additional analysis is as follows: per SVO examination and lab session, it is checked whether materials were collected and if they were, it was calculated how much time is spent on collecting materials from the lab, from the sluice, and all supply actions (including 11c X0) by summing the data of these action. This data is presented in Figure 6 per SVO examinations and lab sessions.

A median of almost one and a half minutes was spent per SVO examination in 18 out of 38 SVOs on getting supplies from the sluice. This costs a total of over 39 minutes for the SVOs with unpacking. If all occurrences (47) of 11c X2 (median of 31 seconds) could be replaced with 11c X1 (median of 18 seconds), a total of just over 10 minutes would have been saved in the observed SVO examinations. In 2024, 3554 SVOs were examined [43] and if 11c X2 had a comparable occurrence frequency, a total of 15.9 hours would have been saved. Additionally, it reduces the occurrence frequency of interrupting SVO examinations to go into the sluice, preventing

TABLE IV: An overview of the ten longest actions observed in SVO phases, with the median and interquartile ranges of $\mathbf{t}_{\text{SVOact}}$ presented in minutes and seconds. Also, $\mathbf{n}_{\text{SVOstep}}$ and the average $\mathbf{n}_{\text{SVOstep/SVO}}$ ± SD are stated.

Phase	Action	Median $\mathbf{t}_{\text{SVOact}}$ (Q1 – Q3) (mm:ss)	$\mathbf{n}_{\text{SVOstep}}$	Average $\mathbf{n}_{\text{SVOstep/SVO}}$ ± SD	SVO examinations with phase
3. Planning	X4: Wait for help	15:38 (11:34 – 19:43)	2	0.07 ± 0.26	28
4b. Examination with Crime-lite	X5: Test marked traces	10:33 (04:12 – 17:07)	5	1.67 ± 2.08	3
3. Planning	X2: Contact help	07:20 (02:19 – 11:15)	3	0.11 ± 0.31	28
2b. SVO unpacking	X1: Read documents	03:48 (03:48 – 03:48)	1	0.03 ± 0.16	39
4b. Examination with Crime-lite	X2: Inspect with Crime-lite	02:27 (01:37 – 04:57)	4	1.33 ± 0.58	3
4b. Examination with Crime-lite	X6: Discuss results	01:59 (00:41 – 06:31)	5	1.67 ± 2.08	3
3. Planning	X3: Consults	01:44 (01:31 – 01:58)	2	0.07 ± 0.26	28
4b. Examination with Crime-lite	X1: Prepare for Crime-lite	01:40 (01:09 – 02:38)	4	1.33 ± 0.58	3
7. Sample kit preparation and handling	X1: Items on sheet	01:39 (00:51 – 02:42)	11	1.00 ± 0.00	11
5b. Non destructive trace collection	X3: Sample with swab	01:32 (01:19 – 01:50)	30	1.11 ± 2.53	27

TABLE V: Overview of flexible phases with their median $\mathbf{t}_{\text{flex}}$ in minutes and seconds and the corresponding average $\mathbf{p}_{\text{flex/data}}$ and $\mathbf{n}_{\text{flex/data}}$. For this analysis, only SVO examinations and lab sessions (excluding SVO examinations) containing the respective phase have been included.

Dataset	Flexible phase	Median $\mathbf{t}_{\text{flex}}$ (Q1 – Q3) (mm:ss)	Average $\mathbf{p}_{\text{flex/data}}$ ± SD	Average $\mathbf{n}_{\text{flex/data}}$ ± SD	Number of datasets
SVO examinations	11a. Additional gloves	03:27 (02:02 – 05:52)	11.1 ± 6.3	18.2 ± 13.5	38
	11b. Facilitating actions for SVO examination	04:33 (03:03 – 06:33)	14.6 ± 8.0	16.3 ± 8.0	38
	11c. Materials management	03:38 (01:30 – 06:53)	10.8 ± 8.3	9.5 ± 7.7	38
	2c. Workflow interruptions and recovery	00:33 (00:09 – 02:29)	1.7 ± 2.7	2.8 ± 2.3	10
Lab sessions	11a. Additional gloves	00:22 (00:09 – 00:26)	0.6 ± 0.6	1.9 ± 1.1	12
	11b. Facilitating actions for SVO examination	00:23 (00:10 – 00:43)	0.8 ± 0.9	1.5 ± 0.6	15
	11c. Materials management	01:23 (00:22 – 02:15)	2.5 ±2.3	2.5 ± 1.7	22
	2c. Workflow interruptions and recovery	02:43 (02:07 – 03:37)	6.0 ± 4.9	1.2 ± 0.4	23

TABLE VI: Overview of the respondents' answers to the questionnaire that were given more than once. The answers are grouped in categories, and the number of respondents and responses is given.

Categories	Answers	Respondents	Responses
Experienced problems	Faulty devices, mainly electronic	6	7
	Material management	5	5
	Communication (availability and reachability)	3	5
	Administrative tasks	7	9
Experienced as labour-intensive	Complex SVO examinations	7	7
	Administrative tasks	5	5
General suggestions for improvement	Fixing devices	7	11
	Improving material management	3	6
	Streamline administrative tasks	7	12
Specific suggestions for improvement	Speech-to-text	3	3
	Easier transfer of photos from camera to computer	4	5
	Automated analysis of microscopic slides	2	3
	Integrating IT systems	3	4

the corresponding frustrations that the examiners may experience.

4.7.2. Processing of sample kits

A total of 9 sample kits were observed. Phase 7 describes the processing of samples and sample kits. During observation, it was noted that actions 7 X1 and 7 X2 took a long time, which was supported by Table IV. The swabs, which come in round containers, are removed from the package and placed on an examination sheet so that the handwritten description can be read. However, because of the round containers, the swabs roll away. When the samples are positioned correctly, a photo is taken, only to turn the samples to take a photo of their numbers, and the process of rolling samples may start again. Subsequently, samples that are not analysed are put back in the package,

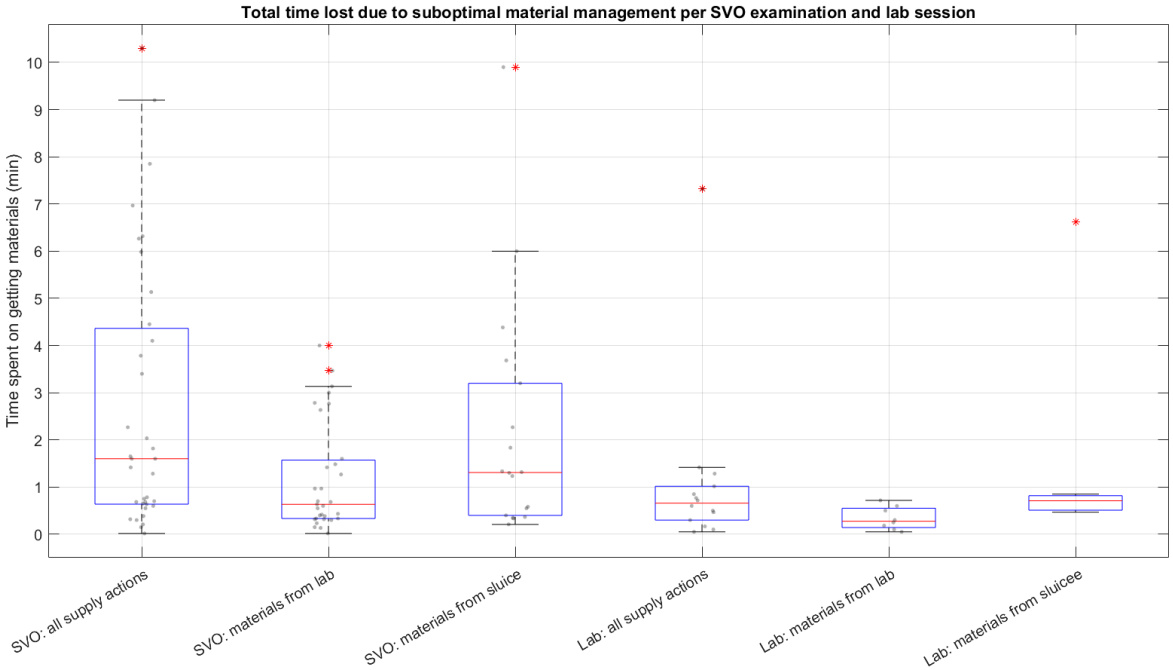

Fig. 5: Boxplots of the total duration of actions to get materials per SVO examination and lab session (with SVO examinations excluded). For each dataset, on the left are all the supply actions combined, including 11c X0. The middle graph shows the action (11c X1) to get materials from the laboratory, and the right one shows the action to get materials from the sluice (11c X2).

and the remaining samples are combined to be photographed, with another chance of rolling away. Furthermore, the descriptions of the samples have to be copied into the report manually. When this process is finished, samples are secured one by one.

This processing of samples has the consequence that the first occurrence of Phase 7 takes a significantly longer time compared to its recurrences, as illustrated in Figure 7, which shows the scattered boxplots of the first occurrence of Phase 7 alongside its recurrences. Only the first occurrence of the phase contains actions 7 X1 and 7 X2, which take comparatively a long time, as shown in Table VII.

Considering sample kits have a high occurrence frequency, especially SAKs (851 out of 3554 SVOs in 2024 [43]), much can be gained by processing samples faster. At the moment, the median $\mathbf{t}_{\text{SVOphase}}$ of the first occurrence is around 8 minutes, with action 7 X1 having a median of 01:39 minutes and action 7 X2 a median of 01:00 minutes. The remaining time is mostly spent on actions of flexible phases (median of 3:18 and IQR of (2:06 – 4:18)): mainly positioning and photographing the samples. If the first occurrence could be processed in half the time (4 minutes), this would have saved up to 56.7 hours in 2024 on the examinations of SAKs alone.

4.7.3. Malfunctioning devices

While the malfunctioning of devices was not directly measured, it was one of the frequent responses given in the questionnaire for questions 5 and 7, respectively, about improvements in daily tasks related to the preliminary examinations and which tools are used frequently that are working suboptimally. The comments were also made during observations by the examiners, but not registering them was an oversight in methodology. However, the responses matched the observations: labels for secured samples could only be printed on certain printers, which sometimes meant examiners had to leave the laboratory to collect stickers. Phones in the laboratory were either not working, which

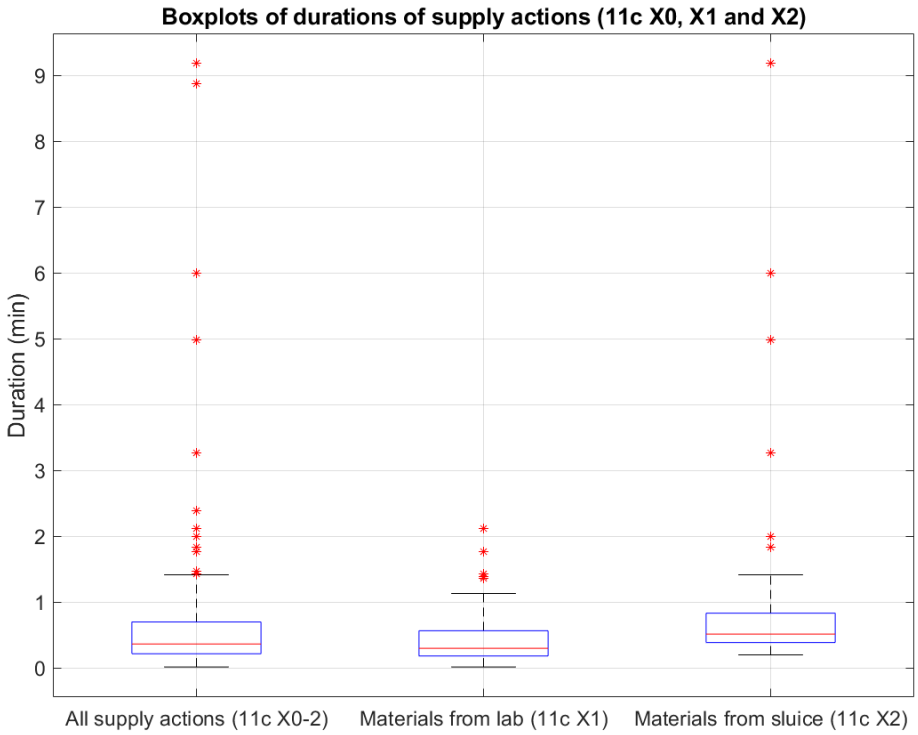

Fig. 6: Boxplots with outliers of the duration of actions to get materials. The left boxplot represents the durations of all the supply actions combined, including 11c X0. The middle boxplot illustrates the action 11c X1: getting materials from the laboratory, and the right one shows the action 11c X2: Getting materials from the sluice. Outliers are marked with a star. An unpaired t-test indicated a significant difference in duration between getting materials from the lab and the sluice ($p < 0.001$).

made reaching out for help more difficult and caused delays, as examiners had to use a phone in another laboratory or leave the laboratory to find the right person. Thus, the malfunctioning of devices often led to unnecessary delays.

4.7.4. Availability and reachability of experts

Even though most examiners were content with the way internal and external communication in the NFI is organised, three examiners mentioned in the questionnaire that it was at times hard to reach experts responsible for the case, or they did not know how to contact them (Phase 3). These responses are supported by limited data, which can be found in Tables IV and VIII. The first table showcases the ten longest actions, of which three actions are indeed related to reaching out for help during Phase 3: 3 X2 and 3 X3 are actions to reach out for help and action 3 X4 is waiting for help. The second table goes into more detail about the three delaying actions, as it shows during which SVO examinations examiners reached out for help, and the $\mathbf{t}_{\text{SVOphase}}$ of when help was contacted and the individual actions that can be considered as a bottleneck. While this bottleneck occurred rarely in the observed SVO examinations, it is likely to occur more frequently during complex SVO examinations, such as multidisciplinary examinations or those involving BPA.

TABLE VII: Actions of Phase 7 and their $\mathbf{t}_{\text{SVOact}}$ in minutes and seconds with the corresponding $\mathbf{n}_{\text{SVOstep}}$.

Phase	Action	Median $\mathbf{t}_{\text{SVOphase}}$ (Q1 – Q3) (mm:ss)	$\mathbf{n}_{\text{SVOstep}}$
7. Sample kit preparation and handling	1	01:39 (00:51 – 02:42)	11
	2	01:00 (00:25 – 01:34)	9
	3	00:10 (00:07 – 00:13)	48
	6	00:45 (00:45 – 00:45)	1

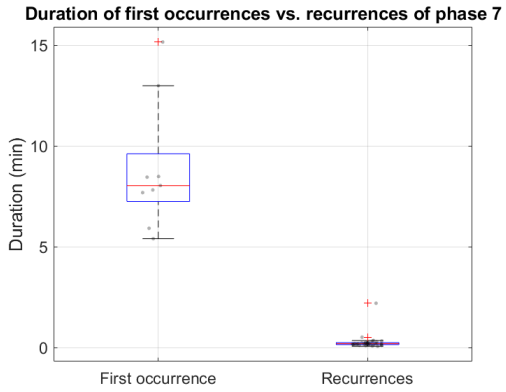

Fig. 7: The $\mathbf{t}_{\text{SVOphase}}$ of the first occurrence of Phase 7 (Sample kit preparation and handling) compared to its recurrences with scattered boxplots including the outliers.

TABLE VIII: Instances where consultation was needed (Phase 3) with the duration of these phases and actions in minutes and seconds.

SVO ID	$\mathbf{t}_{\text{SVOphase}}$ (mm:ss)	X2 (mm:ss)	X3 (mm:ss)	X4 (mm:ss)
SVO 18	00:39	00:39	–	–
SVO 23	31:24	–	01:31	19:43
SVO 24	13:15	–	01:58	–
SVO 25	12:32	12:34	–	–
SVO 57	19:26	07:20	–	11:34

4.8. Long-term solvable bottlenecks

4.8.1. Examination with Crime-lite

Phase 4b (Examination with the Crime-lite) had the longest $\mathbf{t}_{\text{SVOphase}}$ of all phases and contained 4 of the ten longest actions (4b X5, 4b X2, 4b X6 and 4b X1), with Action 4b X5 (test marked traces with AP solution) by far the longest with a median duration of 10:33 as can be seen in Table IV. The examiners were also not content with the workflow, as it was considered labour-intensive, especially action 4b X5. Additionally, examiners complained about the quality of the Crime-lite, mentioning poor battery life, imaging, and ease of use. The marked traces are tested with AP to determine the presence of semen. Examiners try to speed up this process by testing with multiple examiners simultaneously, if possible.

4.8.2. Administrative tasks

Administrative tasks (Phase 8) received the most complaints from the respondents. It was considered labour-intensive and inefficient as tasks had to be repeated in multiple programs. Lastly, transferring photos from the camera to the report was impractical, and the photo-editing tool (Photoshop) was not ideal for marking the sampled areas of the SVOs. During this study, the overall workflow of administrative tasks was created without specific details. Administrative tasks were not the focus of the study, so only the time spent during a lab session was measured. The time spent on administrative tasks varied widely: some examinations were performed by one examiner and almost no time was spent on the computer; in other lab sessions, administrative tasks were executed throughout the whole SVO examination.

5. Discussion

The goal of this study was to determine the detailed workflow of the preliminary examinations of SVOs for human biological traces at the NFI, and to identify and improve the bottlenecks to save time. The detailed workflow was visualised in a flowchart, and the durations of lab sessions, SVO examinations and their phases were analysed. The following bottlenecks were identified in:

- Materials management
- Sample kit processing
- Malfunctioning devices
- Availability and reachability of experts

- Examination with Crime-lite
- Administrative tasks

5.1. Recommendations

5.1.1. Materials management

The suboptimal materials management, primarily due to insufficient stock of products in the laboratory, can be addressed by improving the tracking of stock in the laboratory. The following methods could be applied at BiS in the short term:

- **2 Bin Kanban System**: For each product that should be stocked in the laboratory, two bins are used with a predetermined number of items. When the first bin is emptied, the examiners switch to the second bin. The first empty bin is a clear visual signal that an item needs to be replenished [44].
- **The 5S pillars**: The first step, *Sort*, is determining which products are needed in the laboratory. The second step, *Set in order*, is assigning the needed products to a location for easy and fast retrieval. The third step, *Shine*, is to ensure the cleanliness of the workspace. Once these first three steps are achieved, the fourth step, *Standardisation*, is coming up with a method to manage the first three steps. Possibilities for keeping stock could be placing cards when a product has, preferably almost, run out or noting it on a whiteboard by checking off a product. For this, labels for the right location are a helpful tool [45]. The last step, *Sustain*, is ensuring that the rest of the steps are maintained [46].

For the sluice inventory, it is beneficial to set a minimum stock for each item to ensure replenishment is done on time. For establishing the minimum stock, the estimated delivery time for that product needs to be taken into account so the examiners will not run out in the meantime [47].

5.1.2. Sample kit processing

To reduce the time needed for processing sample kits, two causes of the time delay have to be solved: the rolling away of samples and copying the description of the samples to the report. The first could be solved by creating pronounced ridges on the lid of the round container. Another even easier solution is to create a placemat with ridges or a holder that prevents the samples from rolling away. An important requirement for this tool is that it can be easily cleaned. The second problem could be solved by replacing written descriptions with a code that can be scanned.

5.1.3. Malfunctioning devices

To solve the problem of devices malfunctioning or not meeting the standards, BiS could create a digital log: faulty devices are registered when the examiners experience problems. This updates other users about the problems in each laboratory and organically creates an inventory of the faulty devices that need to be repaired or replaced.

5.1.4. Availability and reachability of experts

To avoid big delays due to reachability and availability issues of colleagues, a solution might be to plan the SVO examinations when the expert involved in the case is also available and mentioned in the SVO-related file. Hence, the examiners know who to reach. Another solution might be that the expert receives an automatic message when the preliminary examination is likely to start and is then expected to be on stand-by (if the expert's availability allows for that).

5.1.5. Examination with Crime-lite

During observations and from the questionnaire, examination with the Crime-lite was found to be labour- and time-intensive. Better technology could be a short-term improvement, but a solution for this bottleneck has not been identified, and further research on this topic is advised.

5.1.6. Administrative tasks

Apart from the suggestions made by the examiners, such as linking systems, speech-to-text, and photo transfer via Wi-Fi, a possible helpful tool might be editing photos on tablets. Now, sample areas are marked with Photoshop with the help of a computer mouse. A touchscreen on which the examiners can draw the sampled area might help. Another suggestion to make reporting easier is a voice recorder app that edits voice recordings with AI into a written report. At the time of this study, this tool is under development internally for reporting

investigations at the crime scene with the help of ing. P. van den Hoven. However, it could also assist examiners at BiS with reporting of the preliminary examinations. For more impactful suggestions, a study can be done on the workflow of administrative tasks.

Currently, Promis is scheduled to be replaced by LIMS. LIMS is an application that is meant to support laboratory workflows and provides documentation of forensic investigation data [48]. It is not yet known what that program will look like for BiS. So, if an additional study is conducted on improving administrative tasks, it would be beneficial in the long run if the study were performed after LIMS is released.

5.2. Limitations of observation

One person, the author, performed this observational study. The work processes of BiS consist of many short actions. It was sometimes difficult to observe all actions, especially when multiple examiners were working simultaneously on an SVO. This led to missing observing short actions such as labelling cups. To ensure the quality of observation, this study focused on examining the SVOs and administrative tasks were recorded as a phase instead of actions. Thus, the data of non-SVO phases is less reliable compared to SVO phases, especially their occurrence frequency.

If actions were missed by the observer and their occurrence and timing could be deduced by using other actions and the timing of photos in combination with time stamps on photos made by the examiners, the observations of actions were still included. Other times, when actions must have occurred but could not be deduced, the duration of the missed action was extrapolated from previous occurrences of the same action. Some actions, mostly with a duration of a couple of seconds, were more often missed than others, especially in Phase 6a: Securing samples. However, the effect of adding missed data of these actions was found to be negligible for the duration of the phase, but it probably has affected the results of action durations.

The preliminary examinations were observed by one observer, with the downside that it was difficult to observe all actions performed simultaneously by the examiners. However, over time, it got easier to observe both SVO and non-SVO phases, since the observer had become more familiar with the workflow. Also, the beginning of an SVO examination was sometimes missed due to timing and limited access to the NFI. The hours when the SVO examinations took place where between 6:15 to 17:30. Examiners started at different times and the observer initially joined around 7:15. After missing too many unpackings of the SVOs, the observer started earlier, however, still a part of a lab session was missed as the examiner began earlier than the observer was allowed (6:30) in the building. The SVO examinations without unpacking were only used to analyse the steps that were observed and the influence of SVO-related variables.

5.3. Limitations of methods

One person, the author, conducted this observational study, which introduces an observer bias and may therefore contain systematic biases. However, having one examiner eliminates interobserver error.

An unrealistic assumption was made by the observer regarding the methodology, that decisions were made instantaneously. In reality, decisions made by the examiners do take time. However, decisions are difficult to measure since examiners perform the actions often back-to-back, making it difficult to distinguish between decision and action.

Per action, it was not registered who performed each action, which made analysing the influence of experience impossible. Considering half of BiS is still learning the ins and outs of the preliminary examination, it probably has affected the durations measured and calculated.

The scope of this study was broad and included a wide variety of SVOs. Subsequently, this led to a frequently adapted flowchart of the detailed workflow until the end of observations. Apart from the split actions in phases 11c and 6a, the actions and decisions of the initial flowchart remained the same. Missing actions and decisions were added to the flowchart, and the organisation of the phases was restructured. After the final version of the flowchart was completed, all observations and their labels were checked, and corrected if the labels of observations no longer corresponded. Every observation was considered a method of validating and optimising the flowchart.

Still, the flowchart's graphical optimisation until the very end suggests that the detailed workflow of the SVO examination has not been fully optimised yet. However, since no major changes, such as adding or restructuring phases, were made since halfway through the observations, it indicates that the flowchart of the detailed workflow is an accurate visualisation for giving an overview of the work processes at BiS. Furthermore, the optimisation of the detailed workflow has not yet been achieved for every type of SVO, because the focus of this study was on the SVO examinations of textiles, human material and weapons. However, because SVO examinations of other types of SVOs were also observed, the detailed workflow provides a sufficient overview for a wide range of SVOs.

An SVO examination was excluded if more than phase 2b was missed during observation. Considering the observations did not take place every working day, SVO examinations that started the day before were not included, as well as three SVO examinations that continued on another day. One observation was not finished because the observation quality of the first part was insufficient, and the other two were missed due to the original plan to only observe on specific days (Monday, Wednesday and Friday). After this, it was agreed upon by both the supervisor and the observer that observing complete SVO examinations whenever possible was crucial for the quality of the data. These selection criteria created a bias for shorter SVO examinations as some long SVO examinations were not included.

Actions 11c X1 and 11c X2 were designed as one in the initial flowchart under the name 'Getting materials', but were later separated during the observation stage after SVO 18. In the data prior to the distinction, it was sometimes possible to determine where the materials where collected from based on the observer's notes during the observations. At other times, it was possible to deduce where examiners collected materials from, as actions that took less than 10 seconds could not have included trips to the sluice. When both methods could not be applied to assign 11c X1 or X2 to an action, it was registered as 11c X0.

Another split was made in Phase 6: 'Securing samples'. Decision 6a Q4 and actions 6a X10 and X11 were added to the flowchart to more accurately portray the actual process in the laboratory. These steps were first included in the actions 6a X3, X4 and X5. These actions were added and extrapolated to the flowchart after SVO 20, by using data that was collected after the distinction was made.

Another limitation of this observational study is that not every second of the lab session is observed and registered. For example, this unaccounted time could have been spent on decision-making or being time-inefficient. Administrative tasks are also not covered from start to finish, as they were often started and finished outside the laboratory. Thus, the data about administrative tasks is an underestimation of the total time spent on these tasks and is used only to analyse the structure of the lab sessions.

For the identification of bottlenecks, the durations of phases and actions, the results of the questionnaire and observations were used. However, the occurrence frequency of actions and phases is not taken into account to calculate the impact of durations. It is possible that a shorter phase or action could be improved by a relatively small amount of time, but because of the high occurrence frequency, it has a high impact on time efficiency.

5.4. Interpretation and implication of results

The influence of SVO-related variables on the duration of SVO examinations was analysed. This showed that the duration of the SVO examination depends on the research question, type of SVO and level of complexity of the SVO examination. A preliminary examination of an SVO is usually administered under the external product code HBS007, regardless of the research question or level of complexity. Since the prices are fixed for external codes, some SVO examinations are relatively expensive for the external party, while others are relatively cheap, given the amount of time they cost. The planning at BiS already keeps in mind the level of complexity of the SVO examination for making the planning, which is based on the research question. These results prove that they are right to do so.

Although the workflow could be improved at a higher level, some issues, such as faulty electronic devices and poor materials management, can already be addressed to enhance the workflow at

BiS. Better materials management might not free up much time per SVO examination. Still, it adds up over the SVO examinations in a year, up to 15.9 hours and makes the workflow less frustrating for the examiners.

Additionally, adjusting the workflow of 'Phase 7: Sample kit preparation and handling' can free up significant time for BiS. Sexual assault cases are one of the most common types of cases received by the NFI, and SAKs are often submitted as SVOs for SVO examination. So, while four or five minutes seems a slight improvement per SVO examination, this will add up over time. A total of 56.7 hours could have been saved that year by reducing the duration of each SVO examination by a couple of minutes.

5.5. *Suggestions for future research*

This study has observed the main aspects of the preliminary examination of the SVO, but not all: BPA, ZF and Amylase prints were excluded from this study, as were the follow-up examinations on collected samples, such as hair analysis and microscopic slides analysis. For a complete overview, these tasks would ideally be added to the detailed workflow. Furthermore, a simulation could also be built to identify bottlenecks that were missed with this workflow analysis.

When the replacement of Promis has been launched, it would be helpful to study the workflow of the administrative tasks as well. According to the results of the questionnaire, a lot of time is spent inefficiently doing administrative tasks.

Lastly, the examination with Crime-lite is currently one of the longest examinations. Further research on how to improve this would be beneficial for BiS.

6. Conclusion

The workflow for the preliminary examination of human biological traces was observed and visualised in a flowchart of the detailed workflow. This study focused on SVO phases, which at times resulted in limited data on non-SVO phases. Additionally, the administrative tasks were only observed as a phase instead of separate actions and only used for the analysis of the lab session structure.

In the short term, the workflow could be improved by better managing materials and electronic devices. Furthermore, Processing sample kits could be less labour-intensive by making a placemat that prevents rolling of the samples and codes to the containers of the samples for faster registration of the samples. Improving these two bottlenecks would, respectively, save up to 15.9 and 56.7 hours a year. The availability and reachability of experts may be improved by aligning their availability with the examination. In the long term, administrative tasks and examinations with the Crime-lite need further research to provide insights to save time.

The duration of SVO examinations is affected by the Category of SVO, the Levels of Complexity and the research question. This should be kept in mind with making the planning for the preliminary examinations of SVO, which is the case at BiS.

This study showed that conducting a workflow analysis by observation provides an understanding of the work processes and their bottlenecks. It also enabled developing fitting solutions for these bottlenecks that can save time in the short and long term, making the workflow of preliminary examinations of SVOs more time-efficient.

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Appendix A

TABLE IX: Brief explanation of each case type that can be received by the NFI.

Private cases	Private investigations, such as post mortem examination
Homicide, Assault, Deaths	Crimes involving fatal outcomes or severe bodily harm
DNA of convicted persons	Registration of the DNA of a convicted person
KLPD missing persons	Investigations surrounding missing persons
Threats against personal freedom, violent	Cases with coercion or threat and violence
Sexual offences, Rape	Sexual assault crimes
Damage and Destruction	Vandalism or destruction of property
Other Destruction and Animal Cruelty	Other destructions and cases where animals were mistreated
Arson, Explosions, etc.	Cases that involve setting fires or explosions
Investigation of fireworks	Criminal cases that involve fireworks
Theft with and without violence	Criminal cases with theft
Burglary (HVC)	Theft in homes or buildings, considered High Volume Crime (HVC)
Vehicle-related (HVC)	Theft of vehicles
Other (HVC)	Theft-related crimes that are not covered by the other theft types
Serious Crime	More severe offences within common crimes, for example armed robbery
Extortion, Fraud, Threats	Crimes without violence that involve financial or psychological deceit
Forgery and Counterfeiting	Falsification of documents or currency
Other crimes under the Criminal Code	Miscellaneous crimes under criminal law, that are not covered by other case types
Terrorism	Crimes against the society
Road Trafic Act = Motor Vehicle Act	Traffic violations
Death/Injury by negligence	Unintended death or injury due to negligence or reckless behaviour in traffic
Other road traffic crimes	Miscellaneous traffic crimes that are not covered by the other case types concerning traffic.
Violation of the Opium Act	Drug-related crimes
Weapons and Ammunition, Firearms	Use or illegal possession of weapons
Miscellaneous, all other cases	Cases that do not fit in the rest of case types
IND-parentage investigation	DNA testing for immigration cases

Appendix B

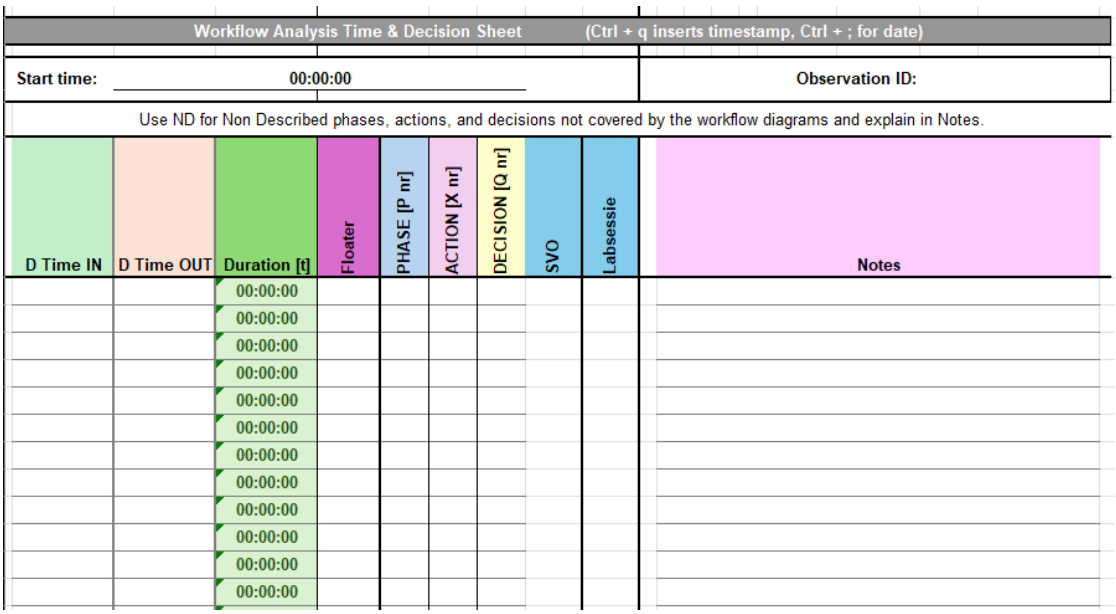

Fig. 8: The observation form used for observation, which was adapted from the study by Loeve et al. [27]

	SVO ID	SVO ID	SVO ID	SVO ID	SVO ID	SVO ID	SVO ID
General info							
Case type							
lab + table							
Examiner 1							
Examiner 2							
Examiner 3							
Experience lab examiner 1							
Experience lab examiner 2							
Experience lab examiner 3							
Examination charachteristics							
External product code							
Internal product code							
Route - Level of Complexity							
Multidisciplinary?							
SVO							
Material							
Colour							
Description							
Promis Description							
Observation							
Research question:							
HBS209? What is examined before?							
ID							
Observation							
SVO							
Case							

Fig. 9: Registration form used to collect all SVO examination-related data. [27]

Appendix C

The questionnaire used for this study is provided below in the original language.

Aanvullende vragenlijst bij de workflow analyse op de divisie Biologische Sporen

1. Hoe lang voert u al uw huidige taken uit?
    - < 1 jaar
    - 1 – 5 jaar
    - 5 - 10 jaar
    - > 10 jaar
2. Hoe lang werkt u op de divisie Biologische Sporen?
    - < 1 jaar
    - 1 – 5 jaar
    - 5 - 10 jaar
    - > 10 jaar
3. Welk onderdeel van uw taken die te maken hebben met SVO's geeft de meeste frustratie?

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.....
.....
.....

4. Wat is het meest arbeidsintensieve van uw werktaken?

.....
.....
.....
.....

5. Wat kan er volgens u worden verbeterd in de dagelijkse of algemene taken die te maken hebben met de SVO's?

.....
.....
.....
.....

6. Zijn er specifieke producten of handelingen met betrekking tot SVO's die verbeterd zouden kunnen worden?

.....
.....
.....
.....
.....

TU Delft

7. Welke tools of systemen gebruikt u regelmatig, en welke daarvan werken naar uw idee niet optimaal?

.....
.....
.....
.....
.....

8. Op welke wijze verloopt de communicatie tussen afdelingen of collega's tijdens het uitvoeren van uw taken?

.....
.....
.....
.....
.....

9. Hoe goed verloopt de communicatie tussen afdelingen of collega's tijdens het uitvoeren van uw taken?

.....
.....
.....
.....
.....

10. Welke stappen in het huidige proces zouden volgens u kunnen worden geautomatiseerd of op een andere manier kunnen worden verbeterd, versneld of vergemakkelijkt met behulp van hulpmiddelen, apparatuur of nieuwe technologie?

.....
.....
.....
.....
.....

11. Heeft u suggesties voor specifieke veranderingen die uw werk zouden kunnen vereenvoudigen?

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.....
.....

Appendix D

TABLE X: Overview of the SVOs with description and assigned categories for factor analysis. Additionally, the experience of the examiners is given as follows: A = less than a year, B = between 1 and 5 years, C = between 5 and 10 years, and D = over 10 years. Lastly, how many laboratory sessions were needed is reported, and whether this SVO included unpackaging.

SVO ID	Description	Category SVO	Material	Case Type	External Product Code	Internal Product Code	Level of Complexity	Research Question	Number of Researcher	Experience Level	Laboratory Sessions	Including Unpacking
SVO 1	Bag	Miscellaneous	Synthetics	Theft	HBS209	BS-V009	IVO	Contact DNA	2	B A	1	•
SVO 2	Hygiene product	Miscellaneous	Textiles	Sexual Assault	HBS007	BS_V007	Complex	Find and collect semen	2	B A	1	•
SVO 4	Pillow	Cushioning	Textiles	Homicide and Assault	HBS209	BS_V009	Complex	Find (and collect) blood	2	B A	1	
SVO 5	Knife	Weapon	Mixed	Homicide and Assault	HBS007	BS_V007	IVO	Find (and collect) blood & Contact DNA	2	B A	2	
SVO 6	Knife	Weapon	Mixed	Homicide and Assault	HBS007	BS_V007	IVO	Find (and collect) blood & Contact DNA	2	B A	2	
SVO 7	SAK	Swabs	Biological materials	Sexual Assault	HBS007	BS_V007	Complex	Processing	2	A A	1	•
SVO 12	Pants	Clothing	Textiles	Sexual Assault	HBS007	BS_V007	Standard	Contact DNA	3	D A A	1	•
SVO 13	Pants	Clothing	Textiles	Sexual Assault	HBS007	BS_V007	Standard	Contact DNA	3	D A A	1	•
SVO 14	Tiewraps	Equipment	Synthetics	Theft	HBS007	BS_V007	Complex	Contact DNA	3	D A A	2	•
SVO 15	Nails	Miscellaneous	Biological materials	Homicide and Assault	HBS007	BS_V007	Complex	Find (and collect) blood & Contact DNA	3	D A A	2	
SVO 16	Pillow cover (pieces of)	Cushioning	Textiles	Other Criminal Offenses	HBS209	BS_V009	IVO	Find (and collect) blood	2	D B	2	
SVO 17	Foam	Cushioning	Synthetics	Other Criminal Offenses	HBS209	BS_V009	IVO	Find (and collect) blood	3	D B A	1	
SVO 18	Pillow cover	Cushioning	Textiles	Other Criminal Offenses	HBS209	BS_V009	IVO	Find (and collect) blood	3	D B A	5	•
SVO 20	Card with envelope	Miscellaneous	Paper	Miscellaneous	HBS007	BS_V007	Standard	Contact DNA	2	B A	1	
SVO 21	SAK	Swabs	Biological materials	Sexual Assault	HBS007	BS_V007	Complex	Processing	2	B A	1	•
SVO 22	SAK	Swabs	Biological materials	Sexual Assault	HBS007	BS_V007	Complex	Processing	2	B A	1	•
SVO 23	Skirt	Clothing	Textiles	Sexual Assault	HBS007	BS_V007	Standard	Contact DNA	2	B A	1	•
SVO 24	Letter of threat with envelope	Miscellaneous	Paper	Extortion and Threats	HBS007	BS_V007	Standard	Contact DNA	2	B A	1	•
SVO 25	Underwear	Clothing	Textiles	Sexual Assault	HBS007	BS_V007	Complex	Find and collect semen & Contact DNA	3	D A A	3	•
SVO 26	SAK	Swabs	Biological materials	Sexual Assault	HBS206	BS_V006	Complex	Processing	3	D A A	1	•
SVO 27	Sock	Clothing	Textiles	Homicide and Assault	HBS007	BS_V007	Complex	Contact DNA	3	D A A	1	•
SVO 28	Sock	Clothing	Textiles	Homicide and Assault	HBS007	BS_V007	Complex	Contact DNA	3	D A A	1	•
SVO 29	Pants	Clothing	Textiles	Homicide and Assault	HBS007	BS_V007	Complex	Contact DNA	3	D A A	1	•
SVO 31	Jacket	Clothing	Textiles	Weapons and Ammuntion	HBS007	BS_V007	Standard	Wearer DNA	2	D A	1	•
SVO 32	Jacket	Clothing	Textiles	Weapons and Ammuntion	HBS007	BS_V007	Standard	Wearer DNA	3	D A A	1	•
SVO 33	Pants	Clothing	Textiles	Weapons and Ammuntion	HBS007	BS_V007	Standard	Wearer DNA	3	D A A	1	•
SVO 34	T-shirt	Clothing	Textiles	Weapons and Ammuntion	HBS007	BS_V007	Standard	Wearer DNA	3	D A A	1	•
SVO 35	T-shirt	Clothing	Textiles	Weapons and Ammuntion	HBS007	BS_V007	Standard	Wearer DNA	3	D A A	1	•
SVO 36	Shoe	Clothing	Textiles	Weapons and Ammuntion	HBS007	BS_V007	Standard	Wearer DNA	3	D A A	1	•
SVO 42	SAK	Swabs	Biological materials	Homicide and Assault	HBS206	BS_V006	Complex	Processing	1	A	1	•
SVO 43	SAK	Swabs	Biological materials	Homicide and Assault	HBS007	BS_V007	Complex	Processing	1	A	1	•
SVO 44	SAK	Swabs	Biological materials	Homicide and Assault	HBS007	BS_V007	Complex	Processing	1	A	1	•
SVO 45	SAK	Swabs	Biological materials	Homicide and Assault	HBS007	BS_V007	Complex	Processing	2	A A	1	•
SVO 46	Bag	Miscellaneous	Synthetics	Other Criminal Offenses	HBS007	BS_V007	Standard	Wearer DNA	2	D A	1	•
SVO 47	Balaclava	Clothing	Textiles	Other Criminal Offenses	HBS007	BS_V007	Standard	Wearer DNA	2	D A	1	•
SVO 48	Gloves	Clothing	Textiles	Other Criminal Offenses	HBS007	BS_V007	Complex	Wearer DNA & Contact DNA	2	D A	3	•
SVO 49	Hair	Miscellaneous	Biological materials	Homicide and Assault	HBS007	BS_V007	Standard	Find (and collect) blood	2	D A	1	•
SVO 50	Tiewraps	Equipment	Synthetics	Other Criminal Offenses	HBS007	BS_V007	Standard	Contact DNA	2	D A	1	•
SVO 51	Swab	Swabs	Biological materials	Sexual Assault	HBS007	BS_V007	Complex	Processing	2	D A	1	•
SVO 53	Part of cobra firework	Weapon	Synthetics	Arson and Explosions	HBS007	BS_V007	Complex	Contact DNA	2	D A	1	•
SVO 54	Firelighters	Equipment	Wood	Sexual Assault	HBS007	BS_V007	Standard	Contact DNA	2	D A	1	•
SVO 55	Swabs (nails)	Swabs	Biological materials	Theft	HBS007	BS_V007	Standard	Find (and collect) blood	1	A	1	•
SVO 56	Jacket	Clothing	Textiles	Theft	HBS007	BS_V007	Complex	Wearer DNA	2	D A	3	•
SVO 57	Pillow case	Cushioning	Textiles	Theft	HBS007	BS_V007	Complex	Find (and collect) blood & Contact DNA	2	D A	4	•
SVO 58	Swabs	Swabs	Biological materials	Theft	HBS007	BS_V007	Standard	Processing	2	D A	1	•

Appendix E

TABLE XI: Overview of all the observed factors and their categories. For each category, the number of observed SVOs is reported with the median duration and interquartile ranges in minutes. Lastly, the last column states the result of the Kruskal-Wallis test.

Factor	Category	Number of SVOs	Median $\mathbf{t}_{\text{SVO-}}$ (Q1 – Q3) (min)	*p*-value
Category of SVO	Clothing	16	28 (10 –56)	.008
	Cushioning	5	406 (130 1515)	
	Equipment	3	15 (9 – 92)	
	Miscellaneous	7	43 (25 – 65)	
	Swabs	11	16 (11 – 26)	
	Weapon	3	200 (53 – 210)	
Material of SVO	Biological Materials	13	19 (12 – 27)	.065
	Metals	2	207 (200 – 213)	
	Paper	2	54 (43 – 64)	
	Synthetics	6	27 (15 – 117)	
	Textiles	21	36 (13 – 168)	
	Wood	1	6.5 (6.5 – 6.5)	
Case Type	Arson and Explosions	1	4 (4 – 4)	.080
	Extortion and Threats	1	64 (64 – 64)	
	Homicide and Assault	12	28 (20 – 80)	
	Miscellaneous	1	43 (43 – 43)	
	Other Criminal Offences	7	129 (19 – 341)	
	Sexual Assault	11	29 (21 – 55)	
	Theft	6	70 (15 – 286)	
	Weapons and Ammunition	6	10 (7 – 14)	
External Product Code	HBS007	38	26 (11 – 64)	.061
	HBS206	2	22 (16 – 28)	
	HBS209	5	147 (67 – 752)	
Internal Product Code	BS_007	38	26 (11 – 64)	.061
	BS_V006	2	22 (16 – 28)	
	BS_009	5	147 (67 – 752)	
Levels of Complexity	1	19	15 (9 – 34)	< .001
	2	20	29 (22 – 99)	
	IVO	6	207 (147 – 406)	
Research Question	Contact DNA	13	35 (22 – 53)	.004
	Find (and Collect) Blood	6	114 (23 – 406)	
	Find (and Collect) Blood & Contact DNA	4	207 (140 – 818)	
	Find and Collect Semen	1	66 (66 – 66)	
	Find and Collect Semen & Contact DNA	1	317 (317 – 317)	
	Not Applicable	10	17 (11 – 26)	
	Wearer DNA	9	10 (9 – 21)	
	Wearer DNA & Contact DNA	1	129 (129 – 129)	
Number of Researchers	1	4	16 (14 – 20)	.436
	2	25	29 (14 – 93)	
	3	16	32 (12 – 99)	

Appendix F

TABLE XII: An overview of the non-SVO actions, with the median duration and interquartile ranges presented in minutes and seconds.

Phase	Action	Median $\mathbf{t}_{\text{labact}}$ (Q1 – Q3) (mm:ss)	$\mathbf{n}_{\text{labstep}}$	Average $\mathbf{n}_{\text{labstep/lab}}$ ± SD	Lab sessions with phase
–	2	00:37 (00:24 – 00:55)	8	1.14 ± 0.38	7
2a. Entering the lab	1	02:32 (01:40 – 02:52)	14	0.88 ± 0.34	16
	2	00:33 (00:18 – 01:26)	13	0.81 ± 0.54	
	3	01:10 (00:56 – 01:40)	15	0.94 ± 0.25	
6b. Process secured traces	1	01:38 (00:55 – 02:37)	15	0.79 ± 0.71	19
	2	00:56 (00:41 – 01:08)	14	0.74 ± 0.73	
	3	00:56 (00:22 – 01:13)	18	0.95 ± 0.52	
	4	00:56 (00:56 – 00:56)	1	0.05 ± 0.23	
	5	00:55 (00:55 – 00:55)	1	0.05 ± 0.23	
	6	00:10 (00:10 – 00:10)	1	0.05 ± 0.23	
10a. Lab clean-up and closure	1	00:50 (00:24 – 02:09)	29	0.97 ± 0.72	30
	2	00:21 (00:15 – 00:32)	22	0.73 ± 0.69	
	3	00:26 (00:14 – 00:47)	16	0.53 ± 0.57	
	4	00:09 (00:05 – 00:19)	40	1.33 ± 1.12	
	5	01:23 (01:00 – 02:08)	41	1.37 ± 1.22	
	6	00:47 (00:43 – 00:52)	30	1.00 ± 0.00	
10b. Logistics of secured traces	3	00:14 (00:07 – 00:26)	11	0.69 ± 0.48	16
	4	00:47 (00:34 – 01:13)	8	0.50 ± 0.63	

TABLE XIII: An overview of the non-SVO decisions.

Phase	Action	$\mathbf{n}_{\text{labstep}}$	Average $\mathbf{n}_{\text{labstep/lab}}$ ± SD	Lab sessions with phase
-	4	18	0.62 ± 1.08	29
	7	46	1.59 ± 0.95	
	8	22	0.76 ± 0.74	
6b. Process secured traces	1	23	1.21 ± 0.54	19
	2	4	0.21 ± 0.42	
10a. Lab clean-up and closure	1	51	1.70 ± 0.99	30
	2	31	1.03 ± 0.18	
	3	19	0.63 ± 1.10	
	4	44	1.47 ± 1.11	
10b. Logistics of secured traces	1	18	1.13 ± 0.34	16
	2	18	1.13 ± 0.34	

TABLE XIV: An overview of the SVO actions, with the median duration and interquartile ranges presented in minutes and seconds.

Phase	Action	Median $\mathbf{t}_{\text{SVOact}}$ (Q1 – Q3) (mm:ss)	$\mathbf{n}_{\text{SVOstep}}$	Average $\mathbf{n}_{\text{SVOstep/SVO}}$ ± SD	SVO examinations with phase
2b. Unpacking the SVO	1	03:48 (03:48 – 03:48)	1	0.03 ± 0.16	39
	2	00:17 (00:05 – 00:31)	38	0.97 ± 0.16	
	3	00:24 (00:16 – 00:35)	36	0.92 ± 0.27	
	4	00:17 (00:11 – 00:24)	27	0.69 ± 0.47	
	5	00:14 (00:10 – 00:31)	28	0.72 ± 0.51	
	6	00:07 (00:04 – 00:10)	24	0.62 ± 0.49	
	7	00:36 (00:27 – 00:43)	25	0.64 ± 0.49	
	10	00:30 (00:12 – 01:41)	5	0.13 ± 0.34	
	11	00:42 (00:17 – 01:05)	30	0.77 ± 0.54	
	12	00:47 (00:23 – 00:55)	3	0.08 ± 0.27	
3. Planning and support	1	01:22 (00:47 – 02:46)	50	1.79 ± 1.40	28
	2	07:20 (02:19 – 11:15)	3	0.11 ± 0.31	
	3	01:44 (01:31 – 01:58)	2	0.07 ± 0.26	
	4	15:38 (11:34 – 19:43)	2	0.07 ± 0.26	
4b. Examination with CrimeLite	1	01:40 (01:09 – 02:38)	4	1.33 ± 0.58	3
	2	02:27 (01:37 – 04:57)	4	1.33 ± 0.58	
	4	00:18 (00:15 – 00:34)	4	1.33 ± 0.58	
	5	10:33 (04:12 – 17:07)	5	1.67 ± 2.08	
	6	01:59 (00:41 – 06:31)	5	1.67 ± 2.08	
4c. Blood examination	1	01:17 (00:40 – 03:06)	106	7.57 ± 11.06	14
	2	00:56 (00:44 – 01:29)	99	7.07 ± 11.34	
	3	00:38 (00:34 – 04:38)	3	0.21 ± 0.80	
5a. Destructive trace collection	3	01:21 (00:59 – 02:19)	34	4.25 ± 1.98	8
	5	00:38 (00:17 – 01:11)	9	1.13 ± 2.10	
	6	00:34 (00:34 – 01:03)	7	0.88 ± 1.81	
	7	01:12 (00:26 – 02:13)	3	0.38 ± 1.06	
5b. Non destructive trace collection	2	01:25 (00:58 – 02:10)	47	1.74 ± 1.99	27
	3	01:32 (01:19 – 01:50)	30	1.11 ± 2.53	
5c. Sampling area selection	1	00:30 (00:21 – 01:29)	27	3.86 ± 4.60	27
	2	00:59 (00:55 – 01:03)	10	1.43 ± 1.51	
6a. Secure traces	1	01:09 (00:38 – 01:34)	28	0.67 ± 2.04	42
	3	00:23 (00:16 – 00:32)	42	1.00 ± 1.47	
	4	00:12 (00:08 – 00:17)	77	1.83 ± 2.84	
	6	00:03 (00:01 – 00:04)	24	0.57 ± 1.68	
	7	00:04 (00:02 – 00:07)	18	0.43 ± 1.21	
	8	00:04 (00:02 – 00:07)	99	2.36 ± 2.46	
	9	00:02 (00:02 – 00:05)	138	3.29 ± 2.72	
	10	00:10 (00:06 – 00:16)	72	1.71 ± 2.57	
	11	00:05 (00:03 – 00:09)	69	1.64 ± 2.31	
	12	00:26 (00:26 – 00:26)	1	0.02 ± 0.15	
7. Kits and swabs	1	01:39 (00:51 – 02:42)	11	1.00 ± 0.00	11
	2	01:00 (00:25 – 01:34)	9	0.82 ± 0.40	
	3	00:10 (00:07 – 00:13)	48	4.36 ± 2.50	
	6	00:45 (00:45 – 00:45)	1	0.09 ± 0.30	
9. SVO finalisation	1	00:56 (00:31 – 01:33)	42	0.98 ± 0.27	43
	2	00:29 (00:14 – 00:30)	3	0.07 ± 0.26	
	3	00:17 (00:11 – 00:39)	9	0.21 ± 0.51	
	4	00:39 (00:28 – 00:55)	40	0.93 ± 0.26	
	5	00:34 (00:22 – 00:37)	7	0.16 ± 0.37	
	6	00:20 (00:16 – 00:28)	31	0.72 ± 0.45	

TABLE XV: An overview of the SVO decisions.

Phase	Action	$\mathbf{n}_{\text{SVOstep}}$	Average $\mathbf{n}_{\text{SVOstep/SVO}}$ ± SD	SVO examinations with phase
-	1	131	3.05 ± 3.57	43
	2	125	2.91 ± 3.48	
	3	143	3.33 ± 2.74	
	5	98	2.28 ± 2.86	43
	6	99	2.30 ± 2.90	
2b. Unpacking the SVO	1	37	0.97 ± 0.28	
	2	23	0.61 ± 0.50	38
	4	25	0.66 ± 0.53	
3. Planning and support	1	49	1.75 ± 1.40	
	2	3	0.11 ± 0.31	28
	3	5	0.18 ± 0.39	
	4	49	1.75 ± 1.40	
4b. Examination with CrimeLite	1	4	1.33 ± 0.58	3
4c. Blood examination	1	231	16.50 ± 23.95	14
5a. Destructive trace collection	1	23	2.88 ± 1.25	8
	2	33	4.13 ± 1.73	
5b. Non destructive trace collection	1	74	2.74 ± 2.51	
	2	30	1.11 ± 2.53	
	3	43	1.59 ± 1.55	27
	4	71	2.63 ± 2.48	
	5	1	0.04 ± 0.19	
5c. Sampling area selection	1	24	3.43 ± 3.95	7
6a. Secure traces	1	117	2.79 ± 2.66	
	2	116	2.76 ± 2.67	
	3	76	1.81 ± 2.85	42
	4	143	3.40 ± 2.73	
	5	137	3.26 ± 2.92	
	6	140	3.33 ± 2.77	
7. Kits and swabs	1	47	4.27 ± 2.61	
	2	48	4.36 ± 2.50	11
	3	11	1.00 ± 0.00	
9. SVO finalisation	1	51	1.19 ± 0.55	43
	2	40	0.93 ± 0.26	

Appendix G

TABLE XVI: Overview of actions that are part of flexible phases. The durations are given in minutes and seconds. Datasets without the action were not used for the analysis of the action.

Phase	Action	Combined datasets		SVO examinations				Lab sessions			
		$\mathbf{n}_{\text{flexstep}}$	Median $\mathbf{t}_{\text{flexstep}}$ (Q1 – Q3) (mm:ss)	$\mathbf{n}_{\text{flexstep/alldata}}$	Number of SVO examinations	Average $\mathbf{n}_{\text{flexstep/data}}$ ± SD	Average $\mathbf{t}_{\text{flexstep/data}}$ (mm:ss) ± SD	$\mathbf{n}_{\text{flexstep/alldata}}$	Number of SVO examinations	Average $\mathbf{n}_{\text{flexstep/data}}$ ± SD	Average $\mathbf{t}_{\text{flexstep/data}}$ (mm:ss) ± SD
11a. Additional gloves	X1	348	00:20 (00:13–00:28)	342	41	8.3 ± 6.7	03:08 ± 02:58	6	6	1.0 ± 0.0	00:21 ± 00:13
	X2	367	00:07 (00:05–00:11)	350	41	8.5 ± 6.5	01:19 ± 01:14	17	11	1.5 ± 0.7	00:13 ± 00:09
11b. Facilitating actions for SVO examination	X1	498	00:15 (00:09–00:30)	495	40	12.4 ± 6.4	04:41 ± 03:50	3	2	1.5 ± 0.7	00:49 ± 00:55
	X2	19	00:12 (00:06–00:27)	–	–	–	–	19	14	1.4 ± 0.5	00:27 ± 00:26
	X3	122	00:07 (00:03–00:17)	122	35	3.5 ± 2.9	00:47 ± 00:53	–	–	–	–
	X4	1	00:12 (00:12–00:12)	1	1	1.0 ± 0.0	00:12 ± 00:00	–	–	–	–
	X5	3	01:13 (00:45–01:15)	3	2	1.5 ± 0.7	01:32 ± 01:21	–	–	–	–
11c. Additional materials	X0	22	00:21 (00:15–00:37)	19	7	2.7 ± 1.8	01:28 ± 01:02	3	3	1.0 ± 0.0	00:34 ± 00:26
	X1	93	00:18 (00:11–00:35)	85	31	2.7 ± 2.1	01:28 ± 01:50	8	8	1.0 ± 0.0	00:20 ± 00:15
	X2	47	00:31 (00:23–00:50)	37	18	2.1 ± 1.3	02:11 ± 02:31	10	8	1.3 ± 0.7	01:24 ± 02:07
	X3	211	00:18 (00:12–00:32)	185	35	5.3 ± 4.1	02:08 ± 01:56	26	17	1.5 ± 0.7	00:52 ± 00:41
	X4	13	00:27 (00:18–00:33)	8	5	1.6 ± 0.9	00:53 ± 01:07	5	5	1.0 ± 0.0	00:30 ± 00:21
	X5	28	00:38 (00:15–01:14)	27	14	1.9 ± 1.7	01:28 ± 01:00	1	1	1.0 ± 0.0	00:44 ± 00:00
	X6	3	03:35 (02:31–06:30)	–	–	–	–	3	3	1.0 ± 0.0	04:24 ± 02:45
2c. Workflow interruptions and recovery	X1	22	02:42 (02:00–03:18)	–	–	–	–	22	21	1.0 ± 0.2	02:51 ± 01:08
	X2	1	00:24 (00:24–00:24)	1	1	1.0 ± 0.0	00:24 ± 00:00	–	–	–	–
	X3	8	00:06 (00:03–00:11)	8	5	1.6 ± 0.9	00:25 ± 00:42	–	–	–	–
	X4	2	00:09 (00:06–00:11)	2	1	2.0 ± 0.0	00:17 ± 00:00	–	–	–	–
	X5	4	00:53 (00:41–01:16)	–	–	–	–	4	4	1.0 ± 0.0	00:59 ± 00:24
	X6	18	00:25 (00:14–00:37)	18	6	3.0 ± 2.0	01:28 ± 01:11	–	–	–	–

Appendix H

This appendix contains a summary of the questionnaire responses, structured per question. The original questionnaire was conducted in Dutch. In this appendix the questions have been translated.

Question 1: How long have you been performing your current tasks?

- Less than one year: three respondents
- 1 - 5 years: two respondents
- 5 - 10 years: zero respondents
- Longer than 10 years: four respondents

Question 2: How long have you been working in the Biological Traces division?:

- Less than one year: two respondents
- 1 - 5 years: two respondents
- 5 - 10 years: one respondent
- Longer than 10 years: four respondents

Question 3: Which part of your tasks related to the SVO causes the most frustration

Recurring suggestions were:

- Problems with technology: physical or IT (four respondents)
- Insufficient supplies in the laboratory which (four respondents)

Other responses were: lack of automatisation, work environment and communication of multidisciplinary examination, photographing with insufficient lighting, and verification that everything is in order.

Question 4: What part of your work tasks is the most labour-intesive?

Recurring suggestions were:

- The administrative part of the examination got the most responses (five respondents), in contrast two people responded that the examination was the most labour-intensive, especially complex SVOs
- Blood examination was mentioned four times
- Examination with CrimeLite was seen as labour-intensive as well, specifically semen as those traces are also tested (three respondents).

Question 5: What could be improved according to you on daily or general tasks related to the SVO?

Recurring suggestions were:

- Six responses were related to IT inefficiency. The promis was seen as laborious, and combining different programmes was also suggested.
- Working technology: such as computers, phones and printers as getting it fixed takes a long time as well (three respondents).

Other responses were the following: better lighting (fingerprint laboratory), better stocking of supplies, and photo transfer via WiFi instead of SD cards.

Question 6: Are there specific products or procedures related to SVOs that could be improved?

Recurring suggestions were:

- CrimeLite: not working well and produces bad quality photos (two respondents)
- Cameras: easier to focus and to transfer photos to the right file on the computer (four respondents)
- Promis was mentioned twice as well.

Other remarks were: better stocking of supplies, working electronic devices, better replacement for photoshop to mark photos, automatic analysis of microscopic slides and RNA analysis of semen, and lastly, optimising the process for additional gloves.

Question 7: Which tools or systems do you use regularly and which of them could be optimised?

Recurring suggestions were (only to be optimised items mentioned here):

- Photoshop is not ideal for editing of photos as needed (two respondents)
- Promis is again mentioned here five times
- Not working computers: either logging is difficult or they do not start up correctly (four respondents)
- : Printers of labels: poor connection and/or unable to print (four respondents)
- : Other electronic devices: cameras, CrimeLites and SD card readers are mentioned to be faulty twice.

Lastly, a respondent also mentioned the stocking of supplies.

Question 8: Suggestions for improvement

Recurring suggestions were:

- By mail (8 respondents)
- By phone (7 repondents)
- In person (8 respondents)

Other digital methods that were mentioned: reports, Promis, Teams, and reporting issues to IT.

Question 9: How good is the communication between departments or colleagues while performing your tasks?

Recurring suggestions were:

- Satisfactory (8 respondents)
- Experts are more difficult to reach (2 respondents)

Other remarks were: at times difficult to reach someone via phone at office, and at times difficult to find the right person.

Question 10: Which steps in the current process do you think could be automated or otherwise improved, accelerated, or made easier through tools, equipment, or new technology?

Recurring suggestions were:

- Connect systems such as Promis and the report to reduce repeating work (4 respondents)
- Speech to text (two respondents)
- Tools that allow for more intuitive handling and visibility (e.g., screen-connected microscopes)

Other remarks were: automatically add ATL buffer and screen-connected microscopes. Other suggestions were already brought up in different questions: easier transfer of photos, automated analysis of microscope slides, better cameras, better stocking of supplies and working electronic devices.

Question 11: Do you have any suggestions for specific changes that could simplify your work?

Recurring suggestions were:

- Better stocking of supplies, in multidisciplinary laboratories as well (2 respondents)
- Working electronic devices (3 respondents)

Other suggestions that were new: log in with employee ID card, serological tests to be performed by another team, automatic microscope slide analysis, better availability of experts, and speech to text for reporting.

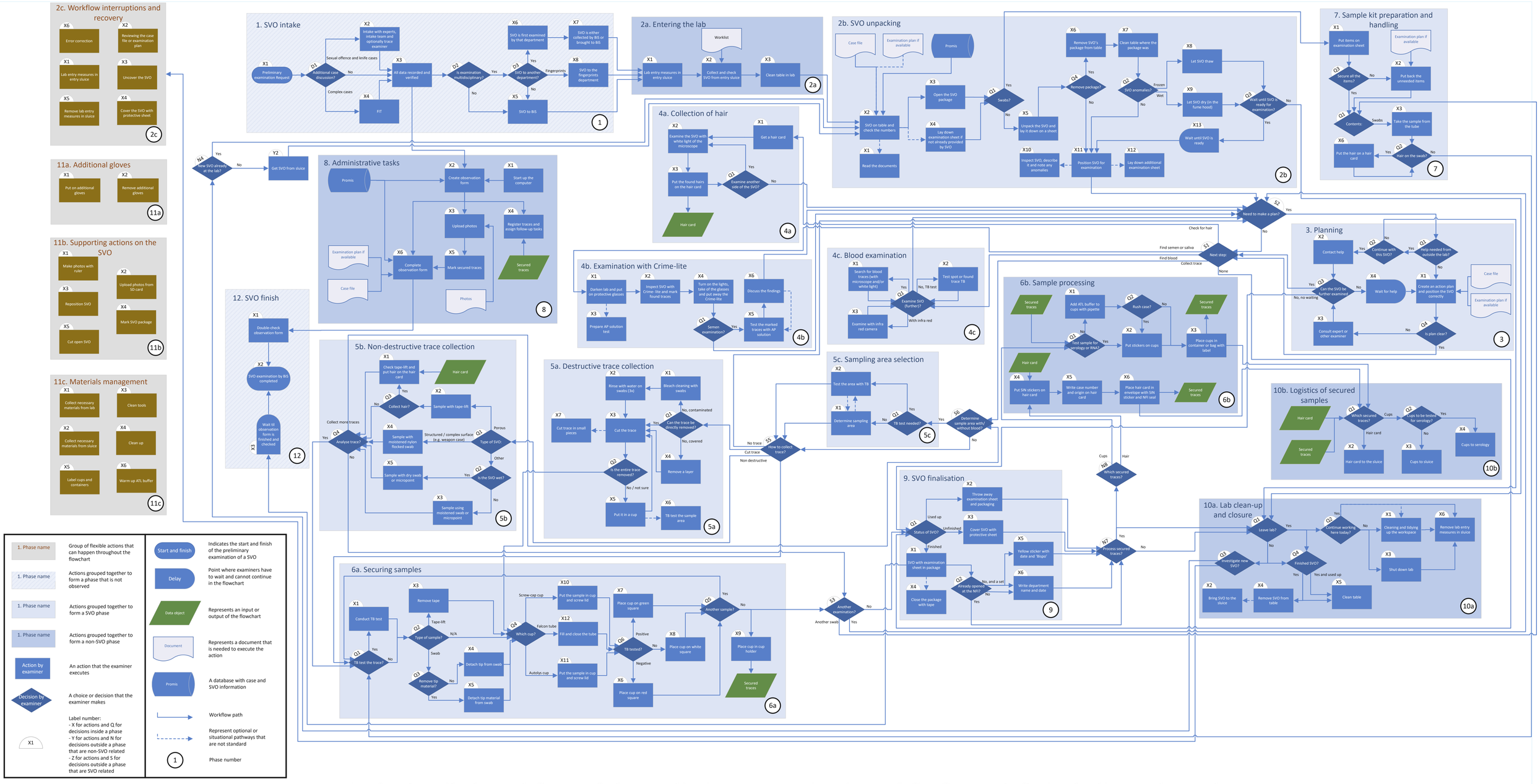

Fig. 3: Detailed workflow of the preliminary examination of SVOs at BIS, including a legend.