The end of the (forensic science) world as we know it? The example of trace evidence

Claude Roux1, Benjamin Talbot-Wright1, James Robertson2, Frank Crispino3 and Olivier Ribaux4

1Centre for Forensic Science, University of Technology Sydney, Broadway, New South Wales 2007, Australia
2National Centre for Forensic Studies, University of Canberra, Australian Capital Territory 2601, Australia
3Département Chimie, biochimie et physique, Laboratoire de recherche en criminalistique, Université du Québec à Trois-Rivières, et Centre international de criminoles comparée, Canada
4Ecole des Sciences Criminelles, University of Lausanne, 1015 Lausanne, Switzerland

The dominant conception of forensic science as a patchwork of disciplines primarily assisting the criminal justice system (i.e. forensics) is in crisis or at least shows a series of anomalies and serious limitations. In recent years, symptoms of the crisis have been discussed in a number of reports by various commentators, without a doubt epitomized by the 2009 report by the US National Academies of Sciences (NAS 2009 Strengthening forensic science in the United States: a path forward). Although needed, but viewed as the solution to these drawbacks, the almost generalized adoption of stricter business models in forensic science casework compounded with ever-increasing normative and compliance processes not only place additional pressures on a discipline that already appears in difficulty, but also induce more fragmentation of the different forensic science tasks, a tenet many times denounced by the same NAS report and other similar reviews. One may ask whether these issues are not simply the result of an unfit paradigm. If this is the case, the current problems faced by forensic science may indicate future significant changes for the discipline. To facilitate broader discussion this presentation focuses on trace evidence, an area that is seminal to forensic science both for epistemological and historical reasons. There is, however, little doubt that this area is currently under siege worldwide. Current and future challenges faced by trace evidence are discussed along with some possible answers. The current situation ultimately presents some significant opportunities to re-invent not only trace evidence but also forensic science. Ultimately, a distinctive, more robust and more reliable science may emerge through rethinking the forensics paradigm built on specialisms, revisiting fundamental forensic science principles and adapting them to the twenty-first century.

1. Introduction

Forensic science has been facing a number of significant challenges in the last 15 years. It has been recently considered to be at a crossroads. While there are many alternative ways of conceiving the discipline [1,2], its future largely depends on if and how a consensus can emerge about its own nature [3]. Without a doubt, the 2009 report of the US National Academies of Science epitomizes the criticisms [4]. In the report, forensic science laboratories and experts are presented as working in a fragmented system under the influence of police enquiries, often using methods and technologies that have been improperly validated. Comparable reports in other countries later made similar findings, like in Canada for example [5]. Furthermore, a number of commentators and academics have made similar criticisms and called for specific academic research, recognizing that attracting significant funding for forensic science research remains a fundamental issue, along with the lack of research and forensic science cultures [6–8]. The crisis is compounded...
by the fact that the effectiveness of forensic science (in the dominant forensics\textsuperscript{1} paradigm based on specialisms) is being increasingly questioned by a number of authors [9–11].

Some authors have questioned whether this forensic science crisis is not rather a collection of symptoms of an unfit paradigm and questioned the effectiveness of commonly proposed solutions that generally target specific problems without reconsidering the way forensic science is taught and learned, researched and operationally applied [2,3]. In addition, the dominant view is that economic rules and business models must regulate practices in forensic science casework. This view continues to impact on the relative importance given to different evidence types, perhaps to the point of phasing some of them out. We ought to add the question: is it the end of the forensic science world as we know it? To facilitate the discussion, this paper focuses on trace evidence as an example.

2. Trace evidence

Trace evidence\textsuperscript{2} is commonly defined [12] at the conceptual level as follows:

— the surviving evidence of a former occurrence or action of some event or agent; and
— a very small amount of substance, often too small to be measured.

At a more practical level, trace evidence is defined as the analysis of materials that, because of their size or texture, transfer from one location to another and persist there for some period of time. Microscopy, either directly or as an adjunct to another instrument, is involved. In this context size matters; typical examples of trace evidence include fibres, hairs, glass fragments, paint chips, soil, botanical traces, gunshot residues, etc. It is beyond the scope of this paper to present or review specialist topics within trace evidence. The reader is instead directed elsewhere, for example Siegel & Saukko [13] or the proceedings of the latest Interpol International Conference on the Forensic Sciences [14].

Trace evidence has the ability to tell a story about what actually happened and who or what may have been involved. For this reason, it is often called the ‘silent witness’. Trace evidence is also at the core of the forensic science process for historical and epistemological reasons. This sub-discipline played a crucial role in the development of forensic science in the twentieth century, prompted by the seminal work of pioneers such as Gross [15], Reiss [16] and Locard [17]. In particular, it is interesting to note that Chapter IV in Locard’s handbook [17] is fully dedicated to trace evidence, and also holds the first expression of what is called Locard’s principle of exchange (see below). Furthermore, there is a recent resurgence of the more general concept of ‘trace’ which itself can help define forensic science as a discipline, because a trace constitutes the most basic material or physical information on crime [18–20].

As with any other trace, trace evidence needs to be detected, seen, and understood to make reasonable inferences about criminal phenomena, investigation or demonstration for court purposes. As remnant of the crime it can, for example:

— provide leads,
— eliminate suspects,
— reconstruct events and their sequence,
— establish charges, and
— identify links in serial crime.

The absence of trace evidence or the presence of a large quantity of trace evidence that does not agree with allegations may have some significance and must be carefully considered in the context of the case under investigation.

Despite all of the above, the value of trace evidence has traditionally been underestimated, and its detection and collection are often neglected due to lack of knowledge, time, resources and challenges in interpretation. As described below, the current forensic science crisis is further pushing the trace evidence sub-discipline close to a breakpoint.

3. Trace evidence and the current forensic science crisis: end of the world as we know it?

(a) Ongoing downgraded status of trace evidence

Interestingly, trace evidence did not attract a great deal of attention in the NAS report, aside from specific criticisms targeted towards specialized topics like microscopic hair examination, for example.\textsuperscript{3} While there is little point expanding upon the reasons for this oversight, it could be hypothesized that trace evidence analysis largely relies on scientific and analytical instrumentation undertaken by tertiary qualified analytical scientists. As such, the scientific underpinnings of this sub-discipline are perceived as robust and well established, unlike those of other areas heavily targeted by recent reviews such as fingerprint identification, handwriting or more broadly identification sciences. Without opening a Pandora’s box, however, a closer look at trace evidence shows that many criticisms or problems identified in other areas of forensic science would equally apply to a sub-discipline also requiring a great deal of experience and cognitive abilities to correctly interpret analytical results and ultimately inform expert opinions.

More interestingly for the purpose of this discussion, the low profile of trace evidence in the NAS report immediately reveals two major stumbling blocks for trace evidence:

(1) end-users may be (too) focused on the identifying dimension of forensic science, which is not the forte of trace evidence; and

(2) trace evidence is primarily perceived to be the endeavour of a high-tech laboratory that necessarily applies well-formalized, time-consuming and costly procedures.

As a result, trace evidence tends only to be considered for high-profile cases as ‘supporting evidence’ and primarily for court purposes. From the outset, this perception hampers innovative contributions of trace evidence to other areas of the law enforcement and criminal justice systems in pursuit of broader security objectives for society. This topic will be discussed further in the next section.

This narrow-minded application of trace evidence betrays a more general and fundamental problem: forensic science seems to be engaged in an out of control spiral forcing the discipline to reduce its scope to a series of service laboratories with limited strict analytical functions, rather than a set of interrelated processes that meet the needs of the security

\textsuperscript{1} paradigm based on specialisms

\textsuperscript{2} is commonly defined

\textsuperscript{3} targeted towards specialized topics like microscopic hair examination

\textsuperscript{4} higher profile cases as ‘supporting evidence’ and primarily for court purposes
and criminal justice systems more holistically [3]. The main cause of this problem has been hypothesized to be the dominant ‘single process view’ concentrating forensic science efforts on risk mitigation of inaccuracy in presenting information in court to deter miscarriages of justice rather than evaluating forensic activity in a broader security framework [3]. The situation is summarized in figure 1.

The problems for trace evidence emerged in fact well before the NAS report. It could be argued that the roots of the current problems go back 40 or 50 years when technological developments started to take precedence over problem-solving in forensic science. Degradation of the holistic view of trace evidence has not halted since then. The sub-discipline first became increasingly fragmented and categorized according to evidence type (e.g. paint, fibres, glass, gunshot residue, geological traces, etc.). Further fragmentation and specialization continued to occur along the boundaries of the techniques used within each trace evidence type. This fragmentation is today institutionalized by the existence of a number of expert working groups (European Network of Forensic Science Institutes (ENFSI) working groups in Europe—e.g. ENFSI Textile & Hair Group, newly established Organization for Scientific Area Committees (OSAC) comprising 23 sub-committees in the USA, etc.) or networks aligned to a particular method or technique (e.g. The Forensic Isotope Ratio Mass Spectrometry—FIRMS), with the absence of a genuine holistic trace evidence group. This occurred despite the loss of the holistic view having been often identified as the major contributor to miscarriages of justice involving trace evidence, the ultimate example being the Splatt case in Australia [12].

From a weakened foundation, the trace evidence sub-discipline has further changed in the last 25 years with the advent of forensic DNA profiling. Forensic science processes and laboratory infrastructures and organizations had to be significantly modified to embrace the ‘DNA revolution’. DNA submerged the holistic perspective in a single trace view of solving cases, based solely on identification, tending to ‘squeeze others out’ [21]. In comparison to DNA, trace evidence is of less identifying value (especially when forensic science is narrowly defined as the science of individualization—limiting the interest to source level identification) and the examination of trace evidence is a costly exercise compared with routine DNA analysis. In other words, the trace evidence community had to adapt and learn to live with less funding and a downgraded status. While this comparison is unfair, if not simply invalid, this relative cost–benefit issue prompted some interesting discussions from various authors in recent years and it may be valuable to summarize some findings in the next paragraphs.

(b) Cost–benefit issue of trace evidence

In the current fiscal climate, forensic science service providers and end-users are impacted by a common system not interested in investing more for the service. This is especially true when the global effectiveness of forensic science is questioned regularly [9–11]. Other studies and estimates show that only a small proportion (10–20%) of the materials recovered at the crime scene make their way to the laboratory [22]. A much smaller proportion of the materials examined in the laboratory (5%) end up in court [21]. If one can expect trace evidence materials to only form a small part of the totality of the forensic materials collected at the start of the process, it is not hard to understand why managers and policy-makers have recently, and increasingly, asked whether maintaining a full service trace evidence laboratory was justifiable [23].

The situation is exacerbated by the fact that the interpretation of trace evidence is generally challenging and may require significant training and R&D capacity to generate the required knowledge base, develop and maintain databases to better assess the relevance of the transferred material and sometimes perform experiments re-enacting the context to clarify points of contention. Additional confusion is created...
in the R&D space by some academic research that is focused on the analytical challenge with little consideration of the real forensic and security contexts. Such research tends to introduce highly specific and complex methods and technologies that are not necessarily fit for forensic science, that are sometimes not necessary and whose integration into forensic science practice is far from being obvious [3]. Overall, more often than not, the value of trace evidence will remain unclear to the non-specialist and of relatively poor cost–benefit to the manager.

For the reasons expressed above, a number of forensic science organizations worldwide reviewed the operations of their trace evidence laboratory, and this often resulted in phasing out some types of examination while keeping the option of outsourcing such examinations for a limited number of high-profile cases only. Such examples include the discontinuation of gunshot residue analysis by the FBI and in Western Australia, of glass examination by the Royal Canadian Mounted Police and recent restrictions in force within the Virginia Department of Forensic Science expected to cut in half the number of anticipated gunshot residue, hair and fibre cases. The list is not exhaustive and seems to be growing. In general, it appears that the strategic directions of the laboratories are based on the number of service requests and time for the examination rather than on scientific grounds. In other words, the evidence types that attract less demand and that are more time-consuming to examine (hence more costly) tend to be culled first. From a pure business viewpoint, the logic seems implausible.

(c) End of the world as we know it for trace evidence?
In this very challenging context, the future of trace evidence is uncertain and, given the lack of consensus about the best model of forensic science delivery, it is difficult to predict its future in any accurate shape or form. We can however confidently argue that the future will be different to what it has been traditionally; i.e. it may well be the end of the world as we know it. As much as the situation is uncomfortable for those involved in this sub-discipline, it also creates a unique opportunity to re-shape trace evidence so it can play a more tangible role in law enforcement and in the administration of justice. Some elements of the solution are discussed in §4.

4. Trace evidence in the ‘new world’: possible solutions?
(a) Revisiting Locard’s Exchange Principle
It has been previously suggested that part of the solution to addressing the forensic science crisis is to look back at the first part of the twentieth century in order to revisit and better understand how the fundamental principles of forensic science have been ignored since then and how these could be adapted in the twenty-first century [2,3,24]. This strategy cannot be more valid than for trace evidence when we consider the well-known Locard’s Exchange Principle:

The truth is that none can act with the intensity induced by criminal activities without leaving multiple traces of his path. […] The clues I want to speak of here are of two kinds: Sometimes the perpetrator leaves traces at a scene by their actions; sometimes, alternatively, he/she picked up on their clothes or their body traces of their location or presence.
Locard [17], ch. IV, translated by the authors

As explained by Ribaux et al. [25], this definition is composed of three main aspects: (i) the nature of the criminal activity influences the types of material that are exchanged, and how they are dispersed in the environment or taken by the offender; (ii) these materials, remnants of the activity, are the traces that become signs when detected, recognized, collected and measured; and (iii) an interpretation process aims at transforming them into clues in order to reconstruct what occurred. This principle has been simplistically translated and engraved as ‘every contact leaves a trace’ in the English speaking world. Unfortunately, this formulation does not take into consideration the nature of the activity and its specific role in the exchange [26]. Nor does it refer to the correct inference rule (‘abductive’ process) that starts from the effects to identify the possible causes—what activity caused the trace? [27]. Conversely, Locard’s original formulation insists on the relationship between the activity and the trace. These observations clearly show the direction for the trace evidence sub-discipline and its end-users: there is little to gain by over-emphasizing source attribution aims with trace evidence; instead trace evidence is a value-added source of information for the reconstruction of a case and more generally to address activity questions [12]. A typical example includes the Tizzone murder in Australia where fibres found on the victim’s shoe soles primarily answered activity questions, namely if the victim had moved a significant distance after being in contact with the source of the recovered fibres [12,28]. The source attribution question was not really considered during the court proceedings.

We should not be shy of the apparent shortcomings of trace evidence in the area of identification and resist the temptation to embark on a never-ending analytical quest delivering results that are often time-consuming to obtain and difficult to interpret. In other words, discrimination is not the most significant feature for trace evidence and focusing the operational and R&D efforts to the identifying dimension as opposed to a more holistic usage of the informational content borne by trace evidence will only worsen the grim situation described above. These efforts should be targeted elsewhere or differently:

— How can we improve the knowledge base needed to better address activity questions through trace evidence?
— How can we address source questions without agonising on discrimination issues?
— How can we better direct investigations through trace evidence?
— How can we integrate trace evidence information with other forensic case data that may be physical or virtual?
— How can we integrate trace evidence information into intelligence and policing frameworks?
— How can trace evidence more broadly contribute to society’s effort in regards to security?

(b) Recapturing the holistic view of trace evidence
Locard was again similarly critical of the move towards specialization, demonstrated by this quote at a time when fingerprint identification was dominating in a manner similar to that in which DNA does today:

Fingerprints are wonderful. I would say (…) it is privileged evidence. But, beyond, one can find prints of a variety of species: tooth print, nails, traces from the entire body, hair, dusts. Dust...
analysis is an infinite, unlimited resource. One can exactly know what the man did [29]. As explained by Ribaux et al. [24], by focusing on one evidence type, offenders would know how to adapt their behaviour to suit. However, they would have difficulty to consciously control all the tracegenic aspects of their actions. In other words, a less specialized treatment of more than one type of trace based on characteristics that are easily recognizable and exploitable is preferable to the specialized in-depth treatment of one type of trace only. With respect to the present discussion, not only does this show that focusing forensic science examinations solely on DNA (or fingerprints), generally for budgetary reasons, may be counter-productive in terms of global policing and security goals, but it also supports removing the over-specialized approach within trace evidence (e.g. glass expert as opposed to paint expert, etc.). Trace evidence experts with a holistic view of forensic science will optimize the value that can be drawn from forensic case data, both from court and intelligence viewpoints. With a holistic process and active management of a case only those trace examinations that have the potential to answer relevant questions would be conducted, minimizing the potential wasted cost of performing trace examinations that are poorly targeted.

Successfully managing the return to the generalist approach will help remove the silos that have been identified in all reviews. Additionally, such generalists may be more effective to lobby for trace evidence in terms of global benefits to policing and justice. In 2008, Delhaan [30] had in fact already identified that the generalists of the 1940s, 1950s and 1960s had been progressively replaced by the 1990s generation of forensic scientists focusing on a specialty, and not appreciating ‘the true role they play’. In other words, it is crucial for trace evidence experts not only to acquire and maintain competencies, skills and experience at the appropriate level of generality, but also to develop and keep a keen interest in the crime situation and investigation, in general. Reflecting on Kind’s work, Ribaux et al. [24] is critical of the pure analytical scientists who bring little value to the investigation if they know nothing about the problem they are supposed to help solve.

Recapturing the holistic view is an area where trace evidence can greatly improve. However, it is recognized that such development is difficult because in many organizations trace evidence experts have been increasingly restricted to providing a simple analytical service about specimens selected and collected by others in response to questions framed by others. We ought to ask the question then: who has the key to this problem? The crime scene. To paraphrase Inman [31], the future of forensic science leads us back to the crime scene.

(c) Recapturing the crime scene as a scientific endeavour

It is traditionally recognized that good forensic science starts at the crime scene. The crime scene is also the place from which most trace evidence will be obtained. As a result, it is impossible to discuss the future of trace evidence without revisiting some critical aspects of the crime scene topic. Indeed, most crucial decisions made at the scene will impact on the relevance, quality and quantity of traces generated by the offenders and made available to further processes. Nevertheless, despite the significant discretionary decision process enjoyed by crime scene examiners, crime scene investigation is often seen as a simple mechanical process: following harmonized procedures should ensure that justice requirements are met in the global chain of custody [25]. At this stage, it is worth quoting DeForest [32]:

We appear to have relegated the framing of questions to non-scientifically educated detectives leaving criminalists with technician functions and fancy hardware, operating in a reactive mode, doing only what is asked of them. This has certainly been the trend. When we take a good look at this model, to which we seem to have grown accustomed, does it make any sense? If the laboratory is set up on the clinical model and crime scenes are handled exclusively by non-scientists, there is no problem-solving scientist on the ‘front end’.

It has also been argued elsewhere that the forensic scientists’ retreat into the laboratory may be one of the causes of the current forensic science crisis, and more so than technical laboratory weaknesses [3]. Integrating crime scene management within the scientific scrutiny has been identified as a way to move forward [33–35]. This has obvious implications for education, training, R&D and recruitment. In this context, it is interesting to note a recent study by Kelty et al. [36], who showed the best crime scene examiners had a university degree, usually in science.

The concept of ‘bringing the laboratory to the scene’ has been around for some time now both in theoretical proposal and technological development [37–39]. The context described above supports the concept further as ‘involving the laboratory in the reflexion regarding crime scene management’. The concept is interesting as it may assist reconnecting the dots, as described later. Recent developments in the analytical chemistry field [40–43] (e.g. lab-on-a-chip—LOC) and the technology market [44,45] (e.g. robotics, drones, etc.) further materialize the concept because they facilitate the deployment of technologies directly in the field. Main examples include DNA analysis, illicit drug and explosives characterization, biometrics and many other treatments. It is not difficult to envisage useful applications in trace evidence: for example, the characterization of a paint chip at the scene of a hit and run and returning the make and model of car on the spot along with a list of all the cars registered and corresponding to this description; or the examination of a fibre thread at a murder scene leading to an almost immediate identification of the type of garment involved and its country of manufacture. Further still, let us imagine the value of such information if it could be cross-referenced to CCTV footage showing a car of a similar make, model and colour travelling close to the accident site; or a person of interest wearing a jacket similar to the description and records of online purchases made for this garment by the same person in almost real-time. And if these examples appear too hypothetical, the reader is directed to the resolution of the Green River Murders in the USA in 2001 [46,47]. During the examination of the victims’ clothing, hundreds of very small coloured spherical particles were found on the clothing of six victims and on the defendant’s work clothing and in his home and work environments. These particles were identified as dried paint droplets of a DuPont high-end specialty product known as Imron. This product had been used at the truck plant where the defendant was employed, and the paint evidence was the basis for charging him with four additional
counts of homicide. However, the original association between the defendant and some of the victims had to be achieved through DNA first. Although considered crucial to associate additional victims with the defendant and securing a guilty plea, unsurprisingly, paint evidence could not lead the investigation despite the fact the information was potentially available on the victims’ clothing. It is not difficult to imagine the value of this information for the case resolution and more broadly crime prevention (given the serial nature of these cases) if such dried droplets could have been quickly detected, recognized and identified to a type of paint used by a truck plant in the area of the murders employing an individual who had been previously identified as a person of interest for the investigation through traditional police methods. It is worth exploring the topic beyond these anecdotal examples in the next paragraphs.

LOC and more broadly ‘bringing the laboratory to the scene’ could be seen as an efficient means of introducing traces into the digital space. The sooner extracted information is made electronic, the sooner it can be effective. Increased automation can improve precision and integrity [48]. Short analysis times and minimal reagent consumption offer reduced logistical demand and reduced costs. More readily accessible trace at the scene may mean more replicates, lower uncertainties, real-time review and opportunity to resample in case of poor quality results. Much like the way digital cameras changed photography, LOC could dispense with the problems encountered when it is discovered later that a specimen was poorly collected, or has deteriorated. For existing practices, this could already represent a potentially huge economic saving and in-built quality control for analyses. Traces previously ignored due to the cost–benefit trade-off under the court paradigm can be collected quickly and cost efficiently as part of a crime management strategy. For intelligence, LOC may bring the necessary capability in a pragmatic enough form to truly enable intelligent investigation. Recovery of traces from the scene and real-time digitization of results may allow feedback from a datacentre indicating links to a possible known modus operandi, and other traces to best allocate time for. From a volume crime perspective, this opens the possibility of monitoring the nature of offences, and detection of emerging series or trends that can be realized as they happen, not simply in hindsight, as current practice and information management prohibits. The possibilities appear endless, ‘only’ limited by the capacity of organizations to manage the exponential amount of data available.

More broadly, blurring the boundaries between the scene and the specialized laboratory is a shift that may partly solve the anomaly expressed by DeForest [32] above, or at least improve it in some ways. In fact, this shift may catalyse a two-way engagement:

1. scientists who, by leaving the traditional laboratory, may be more directly engaged in the field and integrated with the other actors in the security system; and
2. policing and security in general who, by having a more direct access to the detection, analysis and use of forensic case data, may be more pro-actively connected to forensic science.

This shift would be positive as it reconnects forensic science with problems it is supposed to solve. It is nonetheless not without its challenges, the critical one being the lack of tested models for integrating field technologies and forensic databases into well-formed policing and intelligence strategies [24]. Despite the large number of reports available in the analytical literature, the true impact or enhanced capability and efficacy brought by this new capacity to forensic science remains confined to the peripherals and concluding statements of much work, and rarely precedes intention or process to facilitate its integration into routine practices. More research is obviously required to address not only technical aspects, but also criminological, legal, ethical and more broadly sociological and philosophical dimensions. This argument is supported in a recent paper by Stoney & Stoney [49]:

The route towards effective use of new technologies is contrasted with how forensic science laboratories are currently choosing and employing them. The conclusion is that although new technologies are contributing, we are not on a path that will result in their most effective and appropriate use. A new approach is required.

(d) Broadening the applications of trace evidence

Improving the value of trace evidence also requires broadening its applications beyond the traditional court purposes. As the most basic physical information on crime, trace evidence has the potential to bear answers relevant to intelligence, investigative and criminological questions. Neglecting these applications creates a missed opportunity for an area that is desperately trying to discover extension strategies for its survival and, more importantly, a net loss of information for those attempting to solve crime or broader security problems. However, as described above, exploring such applications is not easy in a system that is siloed and almost invariably focused on court purposes. In fact, it appears that some tension exists between these two broad areas of application, as data integration is the key to addressing intelligence, investigative and criminological concerns while extreme fragmentation and specialization seems to be required for court applications. And it is worth remembering that these apparently antagonistic goals should be achieved starting from the same ‘one-off’ trace, the remnant of activity and/or presence. For these reasons, the future of trace evidence also depends on how this duality can be addressed. In the first instance, this calls for the integration of results into suitable processes that can lead to solving problems in a collaborative manner through alternative perspectives. In doing so, the forensic scientist contributes again to solve a specific problem that he is aware of, unlike in today’s fragmented model as described above. Knowing the underlying logical rules is also crucial because these rules are the engine of the collaborative problem-solving process. Conversely, the court dimension requires some sort of specialization at some stage. As already described, this may however only concern an increasingly small number of cases in regards to the total activity.

(e) Trace evidence in the ‘new world’?

As expressed above, it is difficult to validly predict the future of trace evidence. Nonetheless, the observations presented in this section tend to support this hypothetical model: trace evidence in the new world may be primarily treated as frontline detection whose results are contextualized and integrated with other forensic case data to rapidly feed intelligence and
investigation processes in routine casework. The more complete treatment required by courts or to answer complicated questions may be provided later by a centre of specialization or by an outsourced laboratory on an as-needed basis only. The viability and effectiveness of such a model rely on the initial recognition and appropriate treatment of trace evidence at the scene, followed by sound holistic case management, once again replacing the general forensic scientist and crime scene examination at the forefront of the forensic science process.

5. Concluding comments
In the context of the Royal Society meeting entitled ‘The paradigm shift for UK forensic science’, this paper has explored some of the issues faced by forensic science through the trace evidence example and presented some possible solutions. Trace evidence is seminal to forensic science both for epistemological and historical reasons, and most of the comments addressed towards this area are applicable to forensic science as a whole. Despite the fact that many of these comments may appear negative, this paper should not be seen as the ‘nail in the coffin’ of trace evidence. This is in fact quite the opposite. It is hoped that by better understanding the challenges and their roots, the relevant community can work collaboratively with end-users, R&D providers, educators, policy-makers and other stakeholders towards a more effective and more reliable use of trace evidence.

Forensic science has been at the crossroads for some time, and still is. As a result, predicting the future of trace evidence would only be conjecture at this stage. However, the dual role of trace evidence in both the intelligence/investigative and the judicial spaces backed up by many observations presented in this paper tends to support a model whereby trace evidence would be considered as part of frontline detection and whose results could be contextualized and integrated with other forensic case data to rapidly feed intelligence and investigation processes in routine. A centre of specialization or an outsourced laboratory would examine trace evidence further for court purposes on a need basis.

Regardless of whether such a model actually materializes or not, it is argued that sound holistic case management and more central roles for the general forensic scientist and crime scene examination are the keys for a brighter future for trace evidence and forensic science, in general. If the people doing crime scene work and the triage role are brought up and trained to believe trace evidence has a limited role and value then it is hardly surprising if this self-fulfilling prophecy is seen as reality. There needs to be a real focus on training to ensure that trace is recognized, recorded and recovered and its value recognized in the triage or case management phase.

The resurgence of the general forensic scientist does not mean that specialists are not needed. They remain necessary considering the specialized nature of today’s analyses, instruments and some traces. They must, however, be integrated into a coherent and shared reflection about the recognition and effective exploitation of the trace. There is also a need to better express the different logics applied to articulate possible perspectives (intelligence and investigation) or assess results considering hypotheses proposed by others (essentially/globally deductive approach). Solving a specific problem requires the ability to identify the correct underlying logical rules; otherwise, there is a risk of confusing the various roles.

The current situation ultimately presents some significant opportunities to re-invent not only trace evidence but also forensic science. Ultimately, a distinctive, more robust and more reliable science may re-emerge through rethinking the forensics paradigm, learning from past errors, revisiting fundamental forensic science principles and adapting them to the twenty-first century. In summary and in reference to the paradigm shift in the title of the meeting, this would require embracing a number of strategic directions, including but not limited to

- forensic science should not be centred around ‘specialisms’, but on advancing the expertise and knowledge of the trace—the remnant of presence and activity/action;
- forensic science should not be centred on the current laboratory-centric conception of forensic science, but should recapture the crime scene as a scientific endeavour;
- forensic science should be a significant contributor to crime investigation and the resolution of broader security problems;
- forensic science should cover the study of its contribution along the whole chain of the judicial process, from the crime scene, to the presentation of forensic information in court;
- research in forensic science needs an epistemological component for elaborating upon the foundations of an investigative logic exploiting information conveyed by traces;
- research ON forensic science is equally important to research FOR forensic science; and
- forensic science should refocus on problem-solving, which will provide a more central position to the discipline, as well as greater stability and sustainability.

Competing interests. We declare we have no competing interests.

Funding. We received no funding for this study.

Acknowledgements. The authors acknowledge Dr Mark Sandercock, National Forensic Laboratory Services, Royal Canadian Mounted Police, Edmonton, for his comments and feedback in the preparation of the manuscript.

Endnotes
1 Forensics, the dominant model in the most developed countries, is defined as a series of enabling scientific disciplines that assist the criminal justice system as opposed to forensic science that is considered as a distinctive scientific discipline studying traces, the remnant of activity and/or presence, to address problems not only relevant to the court, but also to policing, intelligence and security, in general. In the forensics model, crime scene is considered as a separate police technical activity.
2 The term ‘trace’, as remnant of activity and/or presence is applicable regardless of the size. In addition, the term ‘evidence’ makes reference to court as opposed to investigation or more broadly security concerns. It could therefore be argued that ‘trace evidence’ is a misnomer and that using this term unnecessarily confuses the topic. It would be preferable to use the term ‘microtrace’ that is generally used in German (‘Mikrospur’) and in French (‘microtrace’). However, because of the widespread use of ‘trace evidence’ in the English-speaking world, especially in North America, this term is used throughout this paper.
3 Excluding the overarching comment quoting that ‘With the exception of nuclear DNA analysis, however, no forensic method has been rigorously shown to have the capacity to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source’.
4 Prone to leave (physical and chemical) traces [24].