Simona Francese
Roberto S. P. King *Editors*

Driving Forensic Innovation in the 21st Century

Crossing the Valley of Death

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To my beloved daughter Grace: Courage doesn't always roar; use your quite voice to remind yourself that courage is not absence of fear, it is ploughing through, despite fear; use your loud voice to promise yourself that you will never allow anyone to make you feel small; believe actions, not words, and never forget to be kind to yourself and to others. We all have only one shot at life, make yours count. You are a lioness in disguise. With endless love, mummy.
Simona Francese

To my family: Sometimes we do things not for fame or fortune, but because we truly care. The calling card of life can illuminate even the darkest of pathways and cast shadows over those that doubt you. Never be afraid to question, or dare to try. Success is what ***you*** *make it. For all your love and support, I am indebted to you. For your perseverance and guidance, I respect you. For your strength and tenacity, I admire you.*
Roberto S. P. King

Preface

High-quality, comprehensive research is undoubtedly pivotal to forensic science innovation, yet its transition into the operational domain represents a significant challenge and provides the greatest barrier to innovation.

This book serves to provide a broad and multifaceted understanding of the current forensic science innovation landscape, whilst evaluating some of the enablers, road blockers and barriers to implementation that must be traversed in order to cross the valley of death between 'idea' and its successful implementation.

It is undisputable that forensic science is central in appropriately supporting the criminal justice system. This is especially demonstrated in cold cases, where criminals are continually apprehended, thanks to the technological and scientific advances of the discipline. Notwithstanding, there is a mismatch between this unquestionable truth and the ability to efficiently translate forensic innovation into practice. This dissonance holds true across both the national and international landscapes in different ways, and at different levels, with understandable disparities between the industrial and academic environments. Nonetheless, the underlying issues are very similar and appoint to two fundamental causes:

(1) the lack of a recognition of forensic science as an actual discipline, and
(2) a fundamental lack of appreciation for forensic science as a societal priority.

As a consequence, there is a general lack of dedicated funding, or, alternatively, a misdirection of the funding which may support blue-sky research, but very rarely supports the final steps of the journey, to its implementation.

Moreover, whilst communication channels between end-users (practitioners) and innovators (academia and industry) has notably improved over the last decade, it still lacks a solid framework and structure to support the journey of innovation into the real world. Generating real impact in translating forensic science innovation into exploitable practice necessitates a profound 'bottom-up' paradigm shift, from researchers to policy makers, governmental bodies, policing and research councils.

This book, the first of its kind, is intended to act as a platform to facilitate the dialogue between key innovation stakeholders, namely academia, industry and end-users, to propose a roadmap that serves to facilitate practical developments and offer a revolutionary springboard to initiate the aforementioned paradigm shift.

The book merges the technical and scientific aspects of some of the innovations that have been implemented across forensic science within the national and international landscapes, and with (i) the necessary considerations to take into account on the road to success, such as understandings of cognitive bias, business planning, data privacy and legal and regulatory aspects, (ii) the end-users perspective and (iii) the industry perspective.

The breadth of topics is addressed in a coherent, comprehensive, unique and synergistic manner, such that the challenge of transitioning a forensic science idea to forensic science product/solution has a real opportunity to be addressed. These opportunities will serve to significantly improve the conversion rate of research endeavours into implementable tools thus impacting the criminal justice system in a positive, effective and efficient manner.

Sheffield, UK Simona Francese
Evesham, UK Roberto S. P. King

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About the Editors

Simona Francese is Professor of Forensic and Bioanalytical Mass Spectrometry at Sheffield Hallam University (SHU), UK. She holds a first class honours degree in Chemistry obtained from the University of Salerno, Italy, in 2000, and a Ph.D. in Chemical Sciences awarded in 2004 by the same University. In her current role, she is Director of the Sheffield Multi-Modal Imaging Centre (SMIC) sitting across SHU's Health and Wellbeing and Research and Innovation Colleges and Head of the Centre for Mass Spectrometry Imaging (CMSI) within the SHU's Biomedical Sciences Research Centre.

She is Expert in the development of MALDI MS Imaging applications and has pioneered its development for the analysis of latent fingermarks and blood to profile offenders. More recently, she has engaged in research at the interface between forensics and clinical diagnostics using blood and sweat in fingertip smears to detect cancer and other pathologies.

Her research has been implemented in police casework in UK and Europe and has been partly funded by the Home Office, West Yorkshire Police and The Defence Science and Technology Laboratory, UK, and she is now collaborating with the UK National Health System. She engages in public dissemination at all levels and one exemplary endeavour was the delivery of a TED talk in Vancouver in 2018 on molecular fingerprinting.

Dr. Roberto S. P. King is an Innovator, Technologist and Subject-Matter Expert within forensic science. He was responsible for the product innovation and development portfolio at foster+freeman, UK, where he served as Vice President of Product, and previously as the company's Chief Technology Officer. He gained a first class honours degree in Chemistry and Sports Science from Loughborough University in 2005 and completed his Ph.D. in Chemistry four years later at the same institution. He is a versatile Inorganic Chemist with expertise in the application of chemistry within the forensic arena. His background involves the development of novel fingerprint enhancing agents for use on troublesome substrates, as well as investigation into unique methodologies for evidence recovery from document-based evidence. His current research interests involve fingermarks, body fluids, questioned document examination, trace evidence, and contact transfer. He has a keen interest in exploring long-standing forensic problems using fresh and lateral approaches that encompass all avenues of chemistry, physics and engineering.

He has presented in excess of 200 lectures at scientific events around the world, including both keynote and plenary sessions. He has published more than 30 research papers, three book chapters, and appeared on numerous television and news broadcasts in relation to his work and expertise within the field. He sits on two external Advisory Boards and has led many collaborative research endeavours as Principal Investigator, including both Ph.D. and KTP partnerships. He also holds numerous patents relating to his work within forensic science.

Abbreviations

3Ts	Time, Team, Traction—the proprietary method of Székely Family & Co. to assess maturity of an innovative company
ABFO	American Board of Forensic Odontology
ACE-V	Analysis, Comparison, Evaluation, Verification
ACPO	Association of Chief Police Officers
AFP	Australian Federal Police
AFR	Automatic Face Recognition
AI	Artificial Intelligence
ASBCPA	Anti-Social Behaviour, Crime and Policing Act
ASCLDLAB	American Society of Crime Laboratory Directors Laboratory Accreditation Board
BBC	British Broadcasting Corporation
BCG	Boston Consulting Group
BFEG	Biometrics and Forensics Ethics Group
BMI	Body Mass Index
BPA	Bloodstain Pattern Analysis
BRL	Business Readiness Level is a concept that refers to the maturity of the business considerations developed alongside the technical development of an innovation
BRR	Business Readiness Rate, an assessment method of business capabilities at organizational level, predecessor to BRL
CAST	Centre for Applied Science and Technology
CBRN	Chemical, Biological, Radiological and Nuclear
CBRN-E	Chemical, Biological, Radiological, Nuclear and Explosive
CBRNE	Chemical, Biological, Radiological, Nuclear and Explosives
CCTV	Closed Circuit Television
C-DSM Directive	Copyright in the Digital Single Market Directive
CE	Capillary Electrophoresis
CEO	Chief Executive Officer
CFC	Chlorinated Fluorocarbon
CFRA	Centre for Financial Research and Analysis

ChemCentre	The Chemistry Centre
CIP	Critical Infrastructure Protection
CJEU	Court of Justice of the European Union
CJPOA	Criminal Justice and Public Order Act
CJS	Criminal Justice System
CNN	Convolutional Neural Network
CoS	Centres of Specialization
COSHH	Control of Substances Hazardous to Heath
COVID-19	Coronavirus Disease 2019
CPS	Crown Prosecution Service
CRI	Crown Research Institute
CRM	Customer Relationship Management
CSAFE	Center for Statistics and Applications in Forensic Evidence
CSI	Crime Scene Investigator
DASA	Defence and Security Accelerator
DF	Digital Forensics
DL	Deep Learning
DMCA	Digital Millennium Copyright Act
DNA	Deoxyribonucleic Acid
DOI	Digital Object Identifier
DSA	Digital Services Act
DSTL	Defence Science and Technology Laboratory
EASST	European Association for the Study of Science and Technology
ECHR	European Convention of Human Rights
ECtHR	European Court of Human Rights
EEA	European Economic Area
EIC	Entrepreneurship and Innovation Centre
ENFSI	European Network of Forensic Science Institutes
ESDA	Electrostatic Detection Apparatus
ESR	Environmental Sciences and Research
EU	European Union
EVs	Electric Vehicles
EWCA	England and Wales Court of Appeal
EY	Ernst & Young, one of the big four multinational consulting companies
FCN	Forensic Capability Network
FDP	Forensic DNA Phenotyping
FFR	Forensic Face Recognition
FIGG	Forensic Investigative Genetic Genealogy
FINDS	Forensic Information Database Service
FMEA	Failure Modes and Effects Analysis
FMS	Forensic Management System
FORINT	Forensic Intelligence
FSAC	Forensic Science Advisory Council

FSP	Forensic Science Provider
FSR	Forensic Science Regulator
FSS	Forensic Science Service
FTA	Flinders Technology Associates
FTM	Forensic Technology Manufacturer
FVM	Fingermark Visualization Manual
GCMS	Gas Chromatography/Mass Spectrometry
GDPR	General Data Protection Regulation
GovCo	Government owned company
HFA	Human Face Analysis
HMICFRS	His Majesty's Inspectorate of Constabulary and Fire and Rescue Services
HOSDB	Home Office Scientific Development Branch
HU	Hungary
IAFIS	International Automatic Fingerprint Identification System
ID	Identification
IEC	International Electrotechnical Commission
INTERPOL	International Criminal Police Organization
IP	Intellectual Property
IPO	Initial Public Offering, the first time a company offers its shares at a stock exchange (in public trading)
IPR	Intellectual Property Rights
IR	Infrared
IRA	Irish Republican Army
IRL	Innovation Readiness Level
ISO	International Organization for Standardization
JLS	Joint Legislative Service
KCL	Kings College London
KPMG	Klynveld Peat Marwick Goerdeler Inc., one of the big four multinational consulting companies
KTH	Royal Institute of Technology, Sweden's largest technical university
KTN	Knowledge Transfer Network
KTP	Knowledge Transfer Partnership
LA-ICP-MS	Laser Ablation Inductively Coupled Plasma Mass Spectrometry
LGC	Laboratory of the Government Chemist
LOI	Location of Interest
LSU	Linear Sequential Unmasking
LSU-E	Linear Sequential Unmasking-Expanded
LU	Luxembourg
MA	Master of Arts
MIT	Massachusetts Institute of Technology
ML	Machine Learning
MO	Modus Operandi

MOD	Ministry of Defence
MP	Member of Parliament
MPDD	Missing Persons DNA Database
MPS	Metropolitan Police Service
MS-DOS	Microsoft Disc Operating System
MVP	Minimum Viable Product, the first version of a product which can be sold to customers
NAS	National Academy of Sciences
NAS Report	National Academies of Sciences Report
NASA	National Aeronautics and Space Administration
NDNAD	National DNA Database
NESTA	National Endowment for Science, Technology and the Arts
NFD	National Footwear Database
NGS	Next Generation Sequencing
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NPCC	National Police Chiefs Council
NPIA	National Policing Improvement Agency
NRC	National Research Council
OECD	Organization for Economic Co-operation and Development
OSAC	Organization of Scientific Area Committees
OSP	Online Service Provider
OSRD	Office of Scientific Research and Development
PCAST Report	President's Council of Advisors on Science and Technology Report
PCAST	President's Council of Advisors on Science and Technology
PCP	Pre-procurement is a procurement process phase, covering interactions with suppliers ahead of the issuing of an Invitation to Tender
PCR	Polymerase Chain Reaction
PDS	Police Digital Service
PEERS	A Horizon Europe-funded project delivering transformational change in the EU CBRN-E environment through standardization (https://peers-project.eu/)
PMI	Post-Mortem interval
PoFA	Protection of Freedoms Act
PSDB	Police Scientific Development Branch
PV	Photovoltaic
PwC	PricewaterhouseCoopers, one of the big four multinational consulting companies
QMS	Quality Management System
ROI	Return on investment
SANEs	Sexual Assault Nurse Examiners
SE	Sweden

SEL	Social Embeddness Level, new method that goes beyond Technical Readiness Level (TRL) and assesses the level of societal embeddedness. Developed by TNO
SFC	Székely Family & Co. Kft., a fully-privately owned independent, non-profit start-up studio, incubator and accelerator operating from Hungary across the EU
SGM	Second Generation Multiplex
SIG	Special Interest Group
SME	Small and Medium-sized Enterprises
SNP	Single Nucleotide Polymorphisms
SOP	Standard Operating Procedure
SPACs	Special Purpose Acquisition Companies
SRL	Società a responsabilità limitata, Limited Liability Company in Italian
STAR	Science, Technology Analysis and Research
STR	Short Tandem Repeat
SWOT	Strengths, Weaknesses, Opportunities, and Threats, a common risk assessment method (see more IEC31010:2019—Risk assessment techniques)
TAM	Total Available Market
TLOs	Technology Licensing Offices
TNO	Netherlands Organization for Applied Scientific Research
TRL	Technology Readiness Level
TTOs	Technology Transfer Offices
UAS	Universal Analysis Software
UK	United Kingdom
UKAS	UK Accreditation Service
UKRI	United Kingdom Research and Innovation
UNT	University of North Texas
US	United States
USD	United States Dollar
VLOSE	Very Large Online Search Engine
VMD	Vacuum Metal Deposition
WA	Western Australia
WP29	Article 29 Working Party
WWW	World Wide Web

Chapter 1
The Chicken and the Egg: Research and Innovation Within Forensic Science

Roberto S. P. King

Abstract The chicken and the egg causality dilemma, or chicken and egg paradox, is a longstanding idiom that stems from the observation that all chickens hatch from eggs and all chicken eggs are laid by chickens. It seeks to probe, in a metaphorical sense, situations that lack clarity in what should be considered the *cause* and what should be considered the *effect*. The very nature of the postulation depicts a process of infinite regress, whereby the consequence of one action must depend on the other, and vice versa. To that end, forensic science is widely recognised as a discipline that is fundamentally underpinned by research, upon which the end goal, or application, must be objectively substantiated. In the practical sense, the application of these forensic 'tools' are exploited through innovative solutions that typically take the form of hardware, software, physical techniques, chemical processes, etc. Accordingly, how are new product/process innovations developed in a discipline that is built on the foundations of scientific rigor? Does forensic research solely drive forensic innovation? Do the latest forensic innovations drive the next generation of forensic research? Or do the two co-exist in a symbiotic manner that serves to benefit the process as a whole?

1.1 Research and Innovation

Research is defined as *"the systematic investigation into the study of materials and sources in order to establish facts and reach new conclusions"* [1]. The process of research within forensic science has, like other disciplines, a fundamental emphasis on structured explorations into a defined subject matter(s) in order to understand the consequence of such actions and develop factual conclusions that serve to improve and increase our knowledge. Whilst remaining a relatively small contributor to the 'Life Sciences' sector as a whole, at the time of writing, there are over 50 international journals dedicated to publishing forensic science research articles [2], and, on an annual basis, an order of magnitude more forensic science conferences that are

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focussed on the dissemination of such research conclusions. It is clear that suitable vehicles exist for the sharing of research outputs from forensic science, and such delivery mediums serve as an ideal opportunity for broader collaboration and iterative idea generation. For the most part, such disclosure opportunities are exploited mainly by academic research institutions and forensic practitioners who wish to share the findings of their work either for professional recognition and/or for the benefit it serves the forensic community as a whole. Less so is the involvement, either in person or via publications, of the forensic science technology manufacturer, who is oftentimes the segue between (proof-of) concept and practical exploitation, typically via productisation. Forensic technology manufacturers (FTMs) may regularly have a presence at forensic conferences that include an exhibition annexe, yet their involvement beyond showcasing their products either in the exhibit arena or during a workshop, is typically limited.

Innovation may be considered as "the creation, development and implementation of a new product, process or service, with the aim of improving efficiency, effectiveness or competitive advantage" [3]. Naturally, innovation, or the evolution of innovative offerings, is more plentiful during the embryonic stages of novel subject matter exploration, where new ground and new learnings are commonly encountered. Whilst innovation is often considered to be the fruit of commercial labour, and an opportunity for revenue generation, there exists a bounty of techniques, processes and methods utilised within forensic science that are, by the very definition, innovative. Methods that are used around the world, on a daily basis, where the primary goal is not necessarily to generate financial income, but to improve efficacy, efficiency and applicability of forensic science. Quite often, forensic practitioners must apply innovative thinking and methodology when dealing with unusual items of evidence and crime scenes. FTMs have naturally evolved over the last few decades, developing innovative technologies that serve to improve and expand the capabilities of forensic end users both in the laboratory and in field. For the most part, each manufacturer tends to specialise in one or two forensic 'value streams'—the evolutionary journey from concept to application by the customer. Other larger manufacturers provide a broader range of product offerings that usually have some degree of technical overlap (such as analytical characterisation devices): the likes of Thermo Fisher [4] and Agilent Technologies [5], for example, are recognised for their product portfolio that includes offerings suitable for forensic DNA, Mass Spectrometry, Raman and IR analysis. Manufacturers such as foster+freeman [6], on the other hand, are established as market leaders within the physical forensic sciences; that is in the search and investigation of physical evidence such as Questioned Documents, Fingerprints, Glass, Body Fluids, etc. Naturally, the broader the product portfolio, the more organisational resource required to sustain, develop and support the innovation reaching the marketplace.

1.2 The Research and Innovation Cycle

As illustrated in Fig. 1.1, the act of conducting research and developing innovation are harmonious in their association with technology development. As our knowledge and understanding of a subject matter broadens and develops, it begins to unlock technological enablers that can be built upon to yield a solution. This solution may take the form of a physical device, a piece of software, a process improvement, or one of many other innovative mediums that exist. Ultimately, in the industrial (commercial) setting, it is preferred that the resulting innovation(s) is *usually* monetised in order to directly accrue revenue. With increased revenue and profit generation, comes available cashflow that may be injected back into the business to further develop the research and development programmes that underpin the process [7–9].

Outputs from research within the industrial sector are arguably prioritised differently to those that may be encountered in academia or forensic practice. In the case of the latter, research conclusions are usually disseminated in order to increase awareness of operationally relevant material (the efficacy of traditional fingermark enhancement processes on a new substrate type, for example [10, 11]). Academic institutions, whilst also striving to influence operational undertakings through their work, commonly use their research outputs, which largely take the form of publications and conference presentations, to leverage their applicability for external funding and strengthen the overall impact and stature of the organisation in a highly competitive Higher Education landscape. As with all manufacturers, FTMs are no different in their intrinsic desire to drive revenue and grow the business. Naturally, the size, maturity and ownership structure of the FTM will dictate the specific metrics that must be achieved or maintained, but without revenue and profit generation, the business cannot exist or grow organically. Accordingly, the primary focus of an FTM is that of profitability in any innovation that they develop. The business, as a whole,

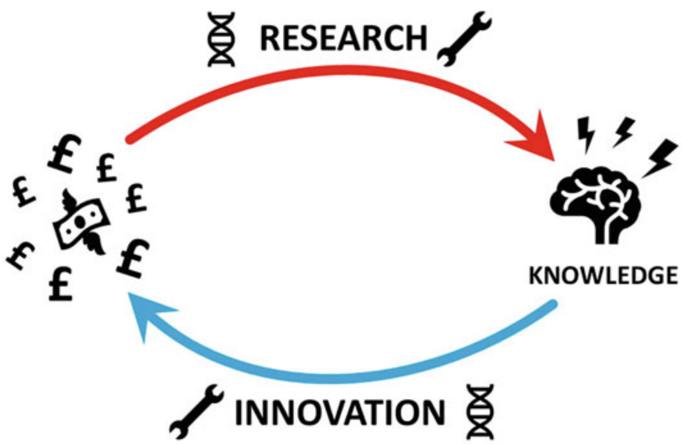

Fig. 1.1 The research and innovation cycle

must therefore work to develop product that offers a competitive edge and then seek to establish it within the market. Research outputs in the form of publications are, to an increasing extent, being recognised as important and powerful vehicles that can underpin commercially focussed ventures through provision of peer-reviewed, scientifically credible and transparent research manuscripts [12–16]. Understandably, the rigors associated with successful publication of research in peer-reviewed journals may allow FTMs to substantiate, to some degree, the credibility and viability of the product developments, whilst also facilitating informed evaluation of the work, and associated innovation, by the community that ultimately seeks to exploit it.

Whilst the benefits of peer-reviewed publications are understood by practitioner and manufacturer alike, it is often a resource limitation that hinders smaller FTMs from venturing down the peer-review journey. This, coupled with the relatively slow publication process (often months), render the prospect of manuscript compilation and submission an unfavoured activity within the commercial forensic sector. A compromise is often achieved through generation of 'white papers' or 'internal application notes' that serve to disseminate research findings via a manufacture-controlled process. Understandably, however, whilst research findings published in this way are of relevance to the forensic community as a whole, and may also be leveraged by end-users to support their technology procurement business case, the acceptance and implementation of such innovation is typically retarded given the perceived absence of independent review.

An additional road-blocker for the FTM in sharing their research and building their scientific pedigree can also stem from the negative perception of commercial participation within educational conferences. For some, the inclusion of FTM representatives within a conference agenda is construed as being too commercial, with undertones of an ulterior (sales) motive. Naturally, whilst there are commercial gains underpinning the very research being presented (and in fact it is primarily the commercial revenue itself that funds the research conducted), the researchers involved in the project(s) have a fundamental intrinsic motivation to share their findings and open-up discussion channels with the broader community. This reciprocity facilitates research evolution and relationship development between industry, academia and practitioner alike. It has the propensity to strengthen the fundamental building blocks upon which we can evolve our understandings and, more importantly perhaps, forensic science practice. Ultimately, the transparency and dissemination of scientifically robust forensic research should be supported through as many means as possible. There must be a representative demographic of research presented at such events, so as to fully appraise the shape and capabilities of the forensic landscape and strengthen opportunities for cross-functional engagement and collaboration.

1.3 Understanding the 'Customer'

The development of new forensic technologies has changed significantly over the last half century [17]. During the embryonic phases of the forensic science discipline, there existed an almost *carte blanche* of capabilities waiting to be developed that were rationalised and brought to life as the significance and importance of our forensic understandings matured. The chemical composition of a latent fingermark, for example, gave way to decades of research into fingermark enhancement reagents. The discovery of genetic fingerprinting and DNA profiling resulted in a paradigm shift across the forensic science research landscape and the race to develop new techniques and technologies to exploit the forensic capability that DNA provided, began. As the outputs of such research endeavours began to be utilised in an emerging discipline, and the resulting impact appreciated, focus naturally centred on process refinement and optimisation of these 'core enablers', rather than a quest for the next 'big thing'.

As such, some of the early FTMs were able to monopolise new process enabling innovation, by productising what would otherwise have remained a laboratory research commodity. Concurrently, these emerging manufacturers helped shape the forensic capabilities of the time. They began broadening their research ventures as a function of the emerging needs of the forensic community and their own appreciation of how technology building blocks could be assembled in a manner to provide new innovation in an otherwise sparse marketplace.

As a function of time, such technologies have naturally developed in a way that serves to automate complex or time-consuming processes and provide effective turn-key solutions. The focus has, to a large extent, been dominated by easing the labour burden on the end user and, in turn, helping to reduce evidence backlogs.

Forensic science itself, and the innovations it utilises, harnesses concepts, processes, technologies and components from wider disciplines, in a manner that is exploited for forensic application. As other more mainstream market sectors develop, so too does the potential for forensic exploitation. To that end, the transformation of forensic technologies in recent years has focussed heavily on deployable instrumentation; products that provide the crime scene examiner with laboratory capabilities. The amalgamation of forensic light sources with high end imaging technology is one such advancement that has recently begun to improve efficiency at the crime scene and help triage evidence in situ, rather than mandating it be analysed back in the laboratory [6]. The importance of arming crime scene investigators (CSIs) with previously considered laboratory technologies must not be downplayed; ensuring both parties have similar capabilities is paramount in maximising evidence recovery and detecting more evidence. An analogous example can be seen in the area of toxicology, where portable analytical devices, such as Raman Spectrometers, are now readily available and have resolving power that is suitably fit-for-purpose in the quest to identify compounds of interest, in field [18, 19].

Despite the breadth of technological offerings at the disposal of the FTM, the art of forensic innovation relies on a journey that is catalysed by a 'problem'. The 'problem' may exist in many forms: from a new class of evidence that requires better detection methods, to the deployment of a technique in an outdoor environment. The 'problem' may present itself to different stakeholders, in different ways:

- time saving
- cost saving
- regulatory compliance
- automation
- fatigue avoidance
- repeatability
- reliability
- functional suitability
- others.

It is also important to consider that quite often, the end users of the technology may not recognise that a problem exists. The daily processes that occur across forensic science are well engrained within the end users. Their familiarity and reliability of such methods may, undoubtedly, constrain their exploration of improved and/or alternative approaches. They may be unaware of synergistic technologies that have the potential to create innovative step-changes within their own discipline and, ultimately, there may even be intrinsic resistance to the acceptance of innovation, should the alternative(s) be perceived to jeopardise the importance of the roles of the individuals concerned.

In contrast, as a discreet entity, the FTM may not necessarily be aware of existing challenges or 'problems' facing their existing/potential end users. Whilst their daily operational focus is that of engineering, manufacture, marketing and sales, the research and product development agenda must be managed in a way that drives continued growth and innovation. It is typical that FTM research and development functions constantly review technology advances in other areas that may be exploited within their own. In essence, it may be considered that the FTM has the 'answers', but are looking for the 'problems', and the forensic practitioner has the 'problem', but is looking for the 'answer'.

Accordingly, it is imperative for the manufacturer to adopt a customer-centric approach to ensure that the correct innovations are developed and delivered in a timely manner and that they fundamentally address the problem(s) at hand. The customers' challenges must be clearly identified (the ***problem***) and solutions (the ***answer***) considered as a function of what is a mandatory requirement (the ***need***) and what may be preferred (the ***want***). The priority with any innovative development is that the offering is functionally capable; it is fit-for-purpose and solves the problem it was designed to. The inclusion of additional features and capabilities, whilst desirable, should not detract or compromise the primary function of the technology. This is especially true for first generation innovations, where the immediate impact should be that of functional capacity, with feature rich offerings typically emerging as iterations of the innovation develop with time.

The archetypical definition of a customer is that of a person or organisation that buys goods or services from an organisation [20]. It is widely construed as the end user; the person who actually uses the product that is purchased. As such, in its simplest form, a customer-centric approach to forensic product innovation would concern itself solely around the use case, or application, that the practitioner is to conduct. Whilst such functionality must of course be at the very heart of any product development, the FTM must also consider other stakeholders as 'customers' to the products, or services, that they develop. To bring a product to market, all facets of the business must be involved in defining the requirement specifications that the product must possess, so that the implementation and execution of technology market introduction is optimised. The product must be designed with many considerations in mind, some of which are entirely independent of the product use case:

- what are the market differentiators for the product?
- what will the sales strategy look like?
- what costing model will be applied?
- how might the forensic procurement process impact on the commercial strategy?
- how will the product be supported in field?
- are there market specific variations that need developing?
- what marketing methods will be employed?
- how will the product be demonstrated?
- what languages must be supported?
- what regulatory governance should be supported?
- how will the supply chain be supported?
- has design-for-manufacture been considered?
- what application studies are required?
- what training will be required (sales, customer support, applications, service, forensic end user)?
- what supporting documentation is required?

Whilst the list above is by no means exhaustive, it does serve to highlight the plethora of factors, and decision-making influences, that must be traversed in order to develop an effective and comprehensive forensic technology innovation in the modern era and, importantly, one that stands the best chance of being widely adopted and relied upon by the forensic end user.

1.4 Collaborative Engagement

Developing a desirable innovation for the forensic laboratory, or crime scene, should not be perceived as a process that is conducted, in isolation, by an FTM (***closed innovation***). Given the broader understanding of who the customer of the product is, the development cycle benefits significantly from a comprehensive stakeholder input to ensure the outputs are aligned to the required need(s) and use case(s). Naturally, the size of the FTM will dictate the resource allocation that is available to develop ideas and concepts internally. Larger organisations may have sufficient personnel to explore such endeavours in detail, drawing on external input at key product design

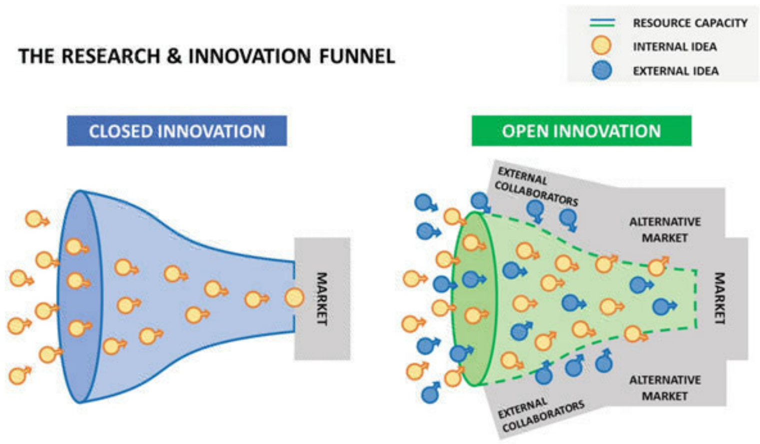

Fig. 1.2 Open and closed innovation funnels

phases where the 'voice of the customer' is critical. Smaller organisations may work more closely with external stakeholders (***open innovation***) in order to bolster their resource and knowledge pool and optimise the efficiency of their innovation process. In essence, both approaches are capable of affording noteworthy innovations, but the input of external stakeholders remains critical to effective product development and market acceptance. It ensures the technology is fit-for-purpose and has been executed with the use-case in mind. The distinction between open and closed innovation workflows, as illustrated in Fig. 1.2, is governed by the methods in which innovation is created.

The latter demands innovation be generated and controlled within the confines of the organisation, whereas and open innovation approach draws more heavily on external stakeholder knowledge and input to drive and support the innovation cycle [21–23].

The demands and benefits of each mode of action differ significantly, with closed innovation requiring the greatest minds of the discipline to be employed by the FTM. It adds significant burden (and overhead) to the manufacturer to ensure its research and development team has all the necessary skillsets and is capable of establishing itself as an industry 'thought-leader', whereby the new ideas and technology that are developed are wholly created, developed, implemented and brought to market by the FTM. The implementation of this approach can often be seen in niche technology sectors, such as forensic science, where unique innovation gives the manufacturer incontrovertible advantages over its competitors. In such instances, the FTM strives to become synonymous with their 'first-to-market' technology and can leverage that impact to substantiate the brand and develop market leadership [24–26]. Organisations that operate under closed innovation boundaries often prefer the control and exclusivity of Intellectual Property (IP) ownership, utilising protective means such as patents, publications and copyrights to deter competitors from stealing product ideas and know-how. Of course, such IP protection is not infallible, and in a discipline where the innovative exploitation of a range of complementary technologies is central to the application, and therefore harder to protect, the costs involved in developing an IP portfolio need to be balanced against the benefits they may be perceived to afford (tax relief, innovation protection, etc.).

Open innovation enables the FTM to broaden its idea generation potential through the strategic utilisation of the wider forensic community. It involves engaging with key opinion leaders and external bodies in an effort to improve the impact of the innovation itself. This may necessitate the collaboration with end users, suppliers, academia, governing bodies and sales partners to maximise the effectiveness of the innovation. Collaborative networking in this way requires extremely well managed project oversight. It is often more challenging to work to efficient timelines, given multiple contributors will likely be involved at any stage of the process. Ultimately, however, the goal here is to develop the very best technology available, by ensuring the very best resources are called upon as and when required. There is much less reliance on the skills and knowledge necessarily residing within the FTM itself. In the United Kingdom (UK), for example, schemes such as the Knowledge Transfer Partnership (KTP), governed by Innovate UK [27], exist to link forward-thinking businesses with the UK's leading academic experts to deliver innovation projects led by inspired graduates. In connecting industry with academia, both organisations benefit greatly in harnessing the complimentary skills and resources that the other possess, in turn delivering impactful innovation as a function of an open and collaborative innovation journey.

Whilst the modes to innovation will vary between FTMs and even on a project-by-project basis, there are key external innovation stakeholders that must be included during the development cycle if the resulting technology is to be effective welcomed. There is perhaps no one more important to garner feedback from than the intended end user (in this case, the forensic practitioner), after all, these are the people that will be utilising the technology on the front-line and have more experience in product application than the FTMs themselves. In addition, an FTM must consider their entire global marketplace and the region-specific needs that are regularly encountered. Product development cannot simply focus on home market requirements, without understanding the potential impact and implementation in other territories, where skillsets, knowledge, challenges, experience, and legislation are likely to be very different and may demand alternative approaches to the way the innovation is delivered.

The relationships an FTM develops with its (potential) end user base is critical to its success not only in innovation development, but in becoming a reliable and dependable source of technology within an ever increasingly competitive forensic sector. The FTM should attempt to engage with practitioners at key touchpoints along the innovation journey in an attempt to understand whether the technology concept is warranted and understood, and how it will likely fit in to, or change, the existing workflows in place. There is, of course, no obligation for end users to engage in such technology developments with an FTM, but in a discipline that strives for scientific excellence and ensuring justice prevails, the community as a whole are extremely receptive to engagement and discussion. Understandably, however, a factor that is often encountered is the requirement for practitioners to remain impartial as part of their tenure within their organisation—that is, not to give 'preferential' advice, guidance or input to a particular commercial entity over another. As such, it can oftentimes be difficult to dive deeply into concept exploration and product development feedback and improvement; the latter typically being the greatest road-blocker between the FTM and practitioner as it is these very suggestions and improvements that are central to iterative product advancements. Undoubtedly, if innovation is to be effective, timely and impactful, barriers between end users and manufacturer need to be navigated in a manner that ensures both parties see tangible benefits. Ultimately, the manufacturer wishes to develop a concept and launch it within the forensic marketplace, and the forensic end user strives to improve their practice and exploit, where suitable, the latest innovations. A certain symbiosis exists as a function of necessity, but that relationship could arguably be deeper rooted through concerted collaborative endeavours that would better arm both parties with the tools and foresight required to develop wholly fit-for-purpose technology, at the right time, with the end user application at the very heart of the product.

1.5 The Research and Innovation Funnel

An FTM must ensure that they possess a balanced product portfolio so that it is well positioned to take advantage of its current and future market growth opportunities. This strategic product roadmap typically seeks to maintain an even combination of new, growing, and mature product offerings. Product oversight using business tools such as the Boston Consulting Group (BCG) Matrix, shown in Fig. 1.3, allow an organisation to review its portfolio and understand where opportunities for improvement exist and how to maximise revenue generation [28, 29].

A balanced portfolio would ideally strive to have products within all categories (except for ***'dogs'***!), so that the ***'cash cows'*** can provide investment funds for the ***'stars'***, which in turn ensure the future success of the business and help turn the ***'question marks'*** into stars. The FTM must seek to hold, build, harvest and divest as a function of their existing portfolio and consider how their research activities are positioned to provide them with market advantage and growth as a function of time.

The research and innovation funnel is a simple concept in which an FTM can assess and review a continuous stream of ideas to ensure those that will likely be most effective and rewarding are developed further, prototyped and ultimately launched as a product. As its name suggests, this process is fed with multiple inputs (ideas) that result in comparatively few outputs (products). As such, it is critically important to feed the funnel with ideas, opportunities, applications, collaborations, etc., so that the organisation has solid foundations upon which to develop its future (forensic) innovation pipeline. A narrow focus at the idea stage, will ultimately result in limitations to innovative scope. Conversely, an over-populated idea pool requires significant

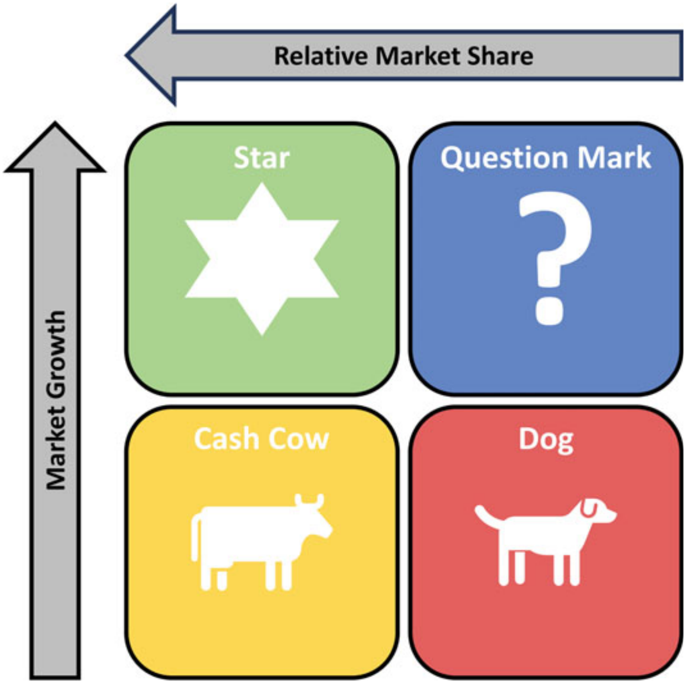

Fig. 1.3 The Boston Consulting Group matrix

resource to evaluate and triage, whilst also creating the potential to dilute impact and scope of chosen product developments.

Idea generation requires input from individuals and functional groups right across an FTMs organisation. It also necessitates inputs, either directly or indirectly, from external stakeholders. The importance of a balanced product portfolio is supported by the importance of a balanced research portfolio. They rely on each other to drive iterative products (new model variants, for example), evolutionary products (next-generation derivatives already present market innovations) and revolutionary products (first of a kind, step-change technology). For this reason, the FTM research roadmap must include a healthy mix of both evolutionary research ideas that can build on existing technology already known to the discipline and within the product arsenal of the manufacturer, and blue-sky concepts that will hopefully move forward to be the stars of the future. The research and development teams must work in unison to develop these ideas and explore them comprehensively from both a feasibility and scientific credibility perspective, given the nature of the target end user. They must also work collaboratively with the commercial arm of the business to understand the product positioning and marketing strategies that will be implemented and, as a consequence of this business alignment, determine the viability and implementation of the product idea.

The development of modern era forensic innovations has seen its focus migrate towards automation and ease of use, with a particular emphasis on process control and feedback. Forensic practitioners still heavily rely on the tried and trusted techniques that have emerged over the last few decades, but with continually inflating evidence backlogs and the scrutiny of forensic best practice ever more in the spotlight, improvements to how evidence is detected, processed, interrogated, and reported has become one of the biggest challenges for FTMs. They need to ensure their modern technologies are scientifically robust and match or exceed the benchmarked state of the art standard, but at the same time deliver elements of automation and ease-of-use, whilst ensuring what happens in the 'background' is recorded in such a way that it can be accessed and reported on as necessary. For example, automated evidence processing, such as the treatment of items within a cyanoacrylate fuming cabinet, can be executed with a single button operation on modern day fuming cabinets [26], but the end user must be able to demonstrate and verify the parameters that were effected by the instrument across a particular treatment cycle. Similarly, the application of image enhancements within a proprietary FTM imaging software suite must detail every function that has been applied to an original image to obtain the result that it subsequently outputs (and may be used in a court of law).

The rigors of laboratory and crime scene 'best practice' in the twenty-first century continues to develop and is largely underpinned by the guidance created in the ISO/IEC 17025 and ISO/IEC 17020, respectively. ISO/IEC 17025 'enables laboratories to demonstrate that they operate competently and generate valid results [30].' This standard is intended to specify the operational requirements for the competence, impartiality and consistency of the laboratory and is applicable to all organisations (falling under, or requiring, the ISO requirements) that conduct laboratory activities. In a relevant capacity, ISO/IEC 17020 specifies the 'requirements for the competence of bodies performing inspection and for the impartiality and consistency of their inspection activities.' This standard is designed to ensure in-field conformity is achieved across a range of 'inspection bodies', which, from a forensic science perspective, relates primarily to crime-scene examination (or anything outside of the laboratory environment). As these standards have evolved over recent decades, not only has the practitioner had to adapt and improve the integrity and transparency of their standard operating procedures, but so too have FTMs had to develop and enhance their technology offerings and capabilities to better align with new and best practices mandated by their end users.

Whilst it is often de facto to consider forensic innovation as a tangible piece of hardware (a new instrument, for example) the effects of ISO/IEC 17025 and ISO/IEC 17020 from an FTM perspective has required the implementation of sophisticated diagnostics and the provision of substantial amounts of data to the end user. As we strive for more automation and more capacity in the technologies we utilise, the forensic regulator understandably requires documentable confirmation that equipment/process is performing as intended (correctly). How these confirmatory checks are implemented in a product will vary from FTM to FTM and from product to product, but ultimately it must be demonstrated that technologies, whether it be