Decreasing Turnaround Time of DNA Analysis by Improving Processes in the Laboratory

Forensic Science Service Ltd. (Birmingham, U.K.), trading as The Forensic Science Service® (FSS®), is a U.K. government-owned company that provides next-generation forensic science to international law enforcement agencies, world judiciary systems, and private sector customers. In a typical year, the FSS handles well over 100,000 criminal cases. This operation involves some 2600 staff in 14 facilities across the U.K. iforensic is the international division of Forensic Science Service Ltd. iforensic has an expanding forensic capability in worldwide markets, with governmental partners in Europe, the U.S., and around the world.

The forensic science undertaken by the FSS covers a wide range of scientific disciplines. The main function is to provide impartial, scientific evidence for use in court. This is usually as a result of a police inquiry, where scientific evidence is needed to help the police with their investigations. This can include:

- Identification of blood, semen, and other body fluids; the blood grouping of dried stains; and the use of DNA profiling to compare samples
- Identification and comparison of textile fibers
- Identification and comparison of plant and animal materials, including hairs
- Analysis of blood and urine samples for drugs or alcohol
- Analysis of body fluids and organs for suspected poisoning
- Identification of illegal drugs
- Comparison of materials used to package drugs
- Examination of paint and glass fragments.

The FSS has a very active Research & Development group that constantly monitors the technology horizon, ensuring that any pertinent technology is used to drive down the time taken to process submissions; enhance the quality of the results; improve value for money; and provide new, innovative solutions to customer requirements. The FSS’s current product portfolio includes world first advances in DNA interpretation, automated DNA profiling, software solutions for data analysis, plus new data extraction systems for mobile phones.

The FSS has driven the evolution of DNA profiling since its introduction as a forensic technique in 1986 (Figure 1). In 1995, the U.K. National DNA Database (NDNAD), the first of its kind in the world, was established. Sample submissions over the first 12 months of operation very quickly exceeded the estimated annual demand of 135,000 samples, resulting in the development of a backlog in excess of 100,000 samples. It became apparent that, with the increase in demand an improved sample tracking process was required to replace the “T”-card system. The “T”-card system provided a central repository for the tracking of samples and batches, with scientists writing the pertinent information on the cards. What the “T”-card system did not offer was a similar central repository for storage location information of individual samples in freezers. This and many other sources of data began to be stored manually on a variety of customized spreadsheets, laboratory notebooks, forms, and paperwork associated with the samples.

In 1996, the FSS developed an internal, very basic LIMS using a spreadsheet application and macros to produce data exports and paperwork associated with the samples and the batches. This computer-based LIMS-type application was continually developed by IT specialists within the FSS and upgraded to include wider aspects of the DNA process, including printable and readable bar codes on paperwork, additional fields for storing data on scientists, reagents, batch numbers, sample types, lot numbers of reagents and chemicals used, sample progress, and even data obtained from instrumentation, such as the amount of DNA contained within a sample.

The reliance on this type of data repository and the increasing need to track samples and batches, while also producing management information on sample turnaround times, numbers of samples processed, and success rates, soon became unmanageable on the spreadsheet systems. The demand for sample processing had also increased.

Based on these requirements, the FSS embarked on the development of laboratory automation, moving forensic DNA profiling into a new era. The onset of automated DNA laboratory processes required, for the first time in a forensic environment, high-throughput use of liquid handling instrumentation, robotic arms, and multiple-well plates. One of the many challenges that had to be overcome was how to log and store information on samples submitted in a 1.5-mL tube format, each individually bar-code labeled, into a multiple-well plate array where, at that time, each individual well could not be bar-coded.
In parallel to the development of the automated processes, the FSS initiated the development of the first forensic DNA LIMS using a commercially available software package. IT developers worked closely with FSS R&D scientists to develop a suite of IT solutions interlinked with the chemistries involved in forensic DNA profiling. Combined, this produced the world’s first DNA profiling line using automated instrumentation, capable of approximately 200,000 forensic reference samples every year.

All relevant components of the automation systems were networked within the FSS’s secure network environment and linked, via server systems, to the LIMS. Access to the system was made available from all workstation terminals so that the data entry and file imports could occur as efficiently as possible during processing.

The U.K. government’s DNA expansion program (April 2000–March 2005) provided £240 million to increase the collection and analysis of DNA material with the emphasis on volume crimes such as burglary and vehicle crime. This increased the demand of DNA profiling and the requirement for a more efficient DNA process.

As a result of this, by 2000, the FSS had encountered a need to further develop the automation systems to increase capacity—demand had increased in the region of 300,000 samples per annum, and there was a need to extend automated processing beyond buccal swabs to other sample types such as chewing gum, cigarette butts, and other sample types that are common in forensic DNA profiling. The new technologies that were developed included modified chemistries for various stages of the process, as well as improved automation that was able to handle samples in a more efficient manner. With the extended sample types that needed to be processed, the LIMS also required modifications to the batch and sample management approach. This included the capability to control the positioning of samples within a batch and ensure that reference samples and unknown (casework) samples were always kept separate. Additionally, there were requirements to separate certain samples from each other within a batch for quality assurance purposes, or to collate other samples together because of their type. These “batching rules” were developed and held in the LIMS, taking it to a new height of full process control.

To complement this development, the FSS recognized that automating the DNA profiling process would bring numerous benefits, including improved speed and efficiency. The DNA profiling process not only incorporated the technical elements but also the interpretation of the resulting profiles. To maximize these benefits, the FSS simultaneously embarked on a program to develop expert DNA profile interpretation systems with the aim of reducing the interpretation workload, leaving the highly skilled staff to focus on those cases requiring expert human interpretation.

In 2005, the FSS implemented FSS-i³, a DNA expert system suite containing i-STRess (a core DNA interpretation tool), i-integrity (an application that provides a full within-batch comparison of profiles that can highlight potential contamination events), and i-stream (a tool for the analysis of simple, mixed DNA profiles; in many laboratories these results are discarded despite containing useful information since the interpretation is deemed to be “difficult”). The benefits this delivered were improved consistency of allele designation, significant reduction in the time required to interpret a batch of DNA data, increased load rate of DNA profiles to the NDNAD, reduction in the unit cost of DNA analysis, fast resolution of two-person mixtures, and release of staff resource to undertake more highly valued examinations. FSS-i³ continues to be upgraded, delivering improvements on the baseline benefits (Figure 2).

Over the years that these DNA lines have been operational, the development of the LIMS has been continual. A number of systems have been generated from the core LIMS, depending on the changing needs of the operational units and the police forces utilizing the service. The complexity of systems has increased to a point where a change to the systems has become a full assessment process with impact analysis. The testing and validation of any changes is ranked according to the impact the change is likely to have on the operational output of the DNA processing laboratory. No change is taken lightly; indeed, a dedicated team within the FSS undertakes the development of changes, troubleshooting of any data issues, validation of changes, and the management of implementation to the operational laboratory following IT industry practices and guidelines for software development.

The FSS is continually improving the service it offers to customers to ensure that it can meet the demanding requirements of rapid and cost-effective service processing. Over the last few years, the FSS has launched many new DNA-related services, including the Forensic Response Vehicle (FRV) and a very rapid, sub-24-hr turnaround time DNA processing service, each requiring significant investment and commitment from the FSS. The DNA processing time within the FRV is approximately three times faster than the more routine high-priority DNA turnaround times already available in the FSS. This has been made possible due to the development and modification of the DNA process, without compromising the integrity of the evidence or the quality of the resulting DNA profile, using the considerable expertise of the FSS.

The FSS FRV pilot was developed in partnership with police forces in England and Wales through the Association of Chief Police Officers (ACPO). It was recognized by everyone that the fast collection and analysis of evidence had the potential to enable the faster apprehension of offenders and dramatically reduce the chance and amount of reoffending. This in turn would have the potential to reduce the cost of investigations, increase the likelihood of securing convictions, and bring benefits to the criminal justice system as a whole. The FRV enabled virtually real-time DNA analysis at the crime scene and was the first of its kind in the world. Developing the FRV required significant investment and commitment from the FSS. The mobile, rapid DNA profiling process presented unique developmental challenges to enable processing in the field, requiring significant specialized development.

As with laboratory-based DNA processing, samples processed within the
FRV were tracked using a LIMS. The FSS chose the Nautilus LIMS (Thermo Fisher Scientific, Informatics Div., Philadelphia, PA) based on its functionality and flexibility coupled with FSS extensions. Fixed batch sizes were replaced with a more flexible series of templates and work flows to accommodate the differing numbers of samples required and demographic information available for each particular case.

The FRVs were used in a pilot with a U.K. police force in 2005. This pilot only included DNA samples collected from burglaries and vehicle crimes and ran for 19 days. In total, 92 DNA samples were processed, the fastest within 7 hr. Of these 92 samples, 51% were searched against the NDNAD, and 65% of them resulted in a match.

The FSS has recently launched a new rapid, laboratory-based sub-24-hr turn-around time DNA profiling service. This is available to police forces across the country and enables the express processing of priority DNA submissions. As with the more routine automated DNA analysis and the FRV, this new rapid process also requires a LIMS that can handle the same data fields and management information but based on a DNA line utilizing different technology and file formats.

LIMS deployed within the FSS are highly functional solutions designed to support complex processes that need to adapt to meet the changing needs of the business. For the FSS, customization has been an essential part of the implementation process. The selection of a LIMS platform that provides a development environment that supports standard rather than proprietary languages with the capability of using “extensions” was key. The FSS is currently using the Nautilus product for this purpose.

The approach currently taken by the FSS to implement a LIMS is to conduct a full review of the requirements of the laboratory to ensure that all considerations are available when reviewing the system. This will enable the package to be configured to allow optimum performance in the environment within which it is utilized. Consideration should be given to the variety of outputs that will be required and their uses and constraints. This will influence where data are held and the structural hierarchy employed within the system. Variations in sample processing can be supported by the creation of several templates and work flows to monitor and control the flow of work within the laboratory from sample log-in through production of final reports. This permits easy configuration of the LIMS to reflect a laboratory process without the need for programming or coding. Sample location can be closely monitored via this process.

Large amounts of data may be easily entered into the Nautilus LIMS automatically or manually. The user interface is based on a Microsoft® Windows Explorer (Redmond, WA) format, allowing manual entry for processes such as sample log-in to be quick and intuitive. Data can be automatically entered into the system by importing and exporting files using the mapping and parsing functionality included with the software; this is particularly useful for integrating the LIMS with an automated robotics system, reducing the possibility of transcription errors and file corruption.

Once held within the database, information can be easily retrieved from the system, either being displayed on screen through a definable folder structure with defined filters or utilizing the reporting tools and generating custom-built output reports for management information or file export.

In addition to the data repository and report generation functions, the LIMS plays an important role in control and validation. Calibration of instrumentation can be monitored from within the system and scheduled, with the ability to prevent work being performed on out-of-service robotic instrumentation. The validation of consumables such as reagents can be stored within the system, which can then regulate certain batches of reagents for use in the process. The security aspect of the LIMS software plays a regulatory role, controlling the access and data available to operators. This enables distinct working practices to be reflected in the system.

The greater control and increased confidence in the system yields greater efficiencies in the process, enabling the DNA profiling division to be more effective as a whole. The division is now well placed and prepared to deal with any future developments in legislation or customer base by utilizing this flexible platform.

The NDNAD currently holds over 4 million DNA profiles. Approximately 12,000 subject samples and approximately 1000 scene-of-crime samples are added weekly. There have been several legislative changes since the introduction of the NDNAD that have allowed for its expansion and have enhanced the power of DNA in detecting crime. The current chance of a profile obtained from a crime scene matching against an individual’s profile already on the NDNAD is approximately 45%. As the FSS has responded to its customers’ demands for fast, cost-efficient DNA processing, it now has the capacity to process in excess of 1,000,000 forensic DNA samples per annum, making it the world’s largest DNA capacity of a single forensic DNA provider.