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Report

to the National

Measurement System

Policy Unit, Department

of Trade & Industry

INTERIM STATUS REPORT

ON THE TIME AND FREQUENCY

AREA

FROM THE SOFTWARE SUPPORT

FOR METROLOGY PROGRAMME

BY

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September 1999

Software Support for Metrology

Interim Status Report on the Time and Frequency Area

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Abstract

This report describes the status of the mathematics and software used to support the Time and Frequency area of metrology, particularly as used within the NMS Time and Frequency programme. This is one of a set of status reports produced for the NMS Software Support for Metrology (1998-2001) programme mid-way through the current programme to inform the formulation of the next SSfM programme (2001-2004). The different aspects of mathematics and software are reviewed under the headings of the themes and project topics of the current SSfM programme. The SSfM programme is identifying best practice where it exists and disseminating guidance on that best practice to other metrology areas. The outputs of the SSfM programme will be generic, applicable to more than one metrology area. This report, therefore, not only identifies problems to be tackled and best practice to be disseminated by the SSfM programme, but also if appropriate possible future Time and Frequency programme projects applying SSfM outputs to specific problems in the Time and Frequency area.

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1 Introduction

The purpose of this status report is to inform the NMS Software Support for Metrology (SSfM) programme about the status of the mathematics and software used to support the **Time and Frequency** area of metrology, particularly what is used within the **NMS Time and Frequency (T&F) programme**. This and the companion status reports for the other metrology areas will inform the formulation of the next SSfM programme (2001-2004). It should also lead to appropriate linkage between the T&F programme and the SSfM programme.

The SSfM programme is an underpinning programme that provides generic support in the use of software and mathematics to the NMS programmes for each metrology area. For details of the programme, its expected deliverables and the results already produced, see the SSfM web site: http://www.npl.co.uk/ssfm/.

The NMS programmes for specific metrology areas provide metrological support to industry. The SSfM programme in contrast has relatively little direct impact upon industry, although there is some as evidenced by the SSfM Club membership. This relationship is depicted in Figure 1. It is because of this relationship that the Status Reports concentrate primarily on the use of software and mathematics in the other NMS programmes.

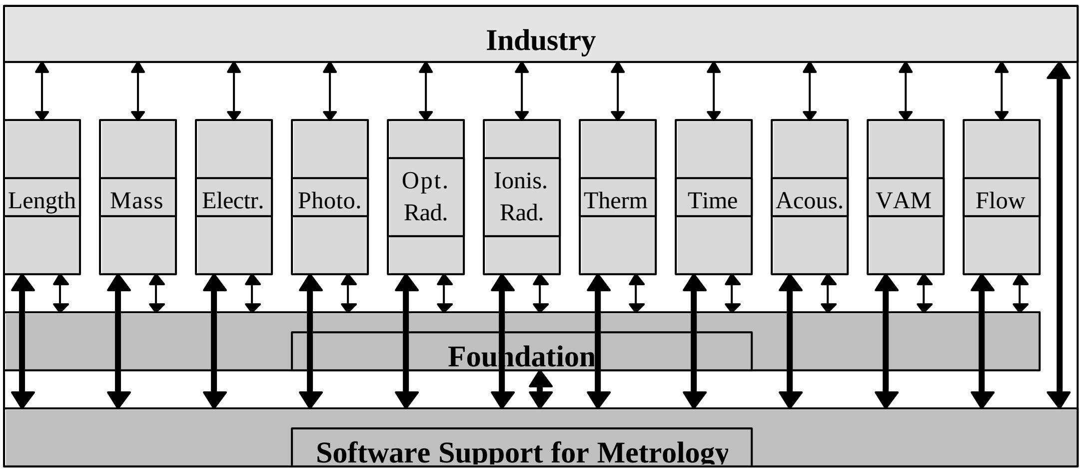

Figure 1. Relationship of SSfM to other NMS programmes and Industry

In particular, this report addresses each of the themes within the SSfM programme and describes the status concerning the topics covered by each of the relevant projects. It also considers whether there are any important software or mathematics issues in the T&F programme which are not addressed by the current SSfM programme or which need to be taken further in the next SSfM programme.

This report is an update of an initial restricted status report produced in November, which was synthesised into an overall status report for all metrology areas and published in February 1999 [1]. A summary of the differences from the initial T&F status report is provided towards the end of this report.

2 Scope of the Area Covered

The NMS T&F programme carried out by NPL's Time Section runs from October 1997 to October 2000. Its objectives are:

1. To maintain and develop the UK national time and frequency standard, UTC(NPL), and relate it to Co-ordinated Universal Time UTC through the International Bureau of Weights and Measures (BIPM).
2. To provide ready access to UTC(NPL) in a variety of formats appropriate to the major time and frequency user communities in the UK.
3. To provide and disseminate information and advice on time and frequency matters to the time and frequency user communities in the UK.
4. To develop improved time and frequency transfer methods for comparing international standards.
5. To develop improved time and frequency transfer methods for the benefit of UK users.

The programme objectives are addressed through a number of different projects, deliverables and milestones. Some programme activities are particularly affected by SSfM issues, while are others are less so. To give an indication of the practical ways in which SSfM impinges on T&F programme, some of the more relevant activities being undertaken by SSfM staff are listed below (together with an indication of the relevant SSfM theme):

OBJECTIVE 1: maintaining the UTC(NPL) time scale

- developing an improved UTC(NPL) software interface (*Metrology Software Development*)
- developing time scale algorithms (*Modelling Techniques*)
- reviewing uncertainties in T&F systems (*Modelling Techniques*)

OBJECTIVE 2: disseminating the UTC(NPL) time scale

- NPL broadcasts (the MSF 60 kHz time signal, the TRUETIME computer telephone time service, and a new GPS common-view time transfer service) interface (*Metrology Software Development*)
- NPL 'calibrations' of standard time & frequency signals received in the UK (*Support for Measurement and Calibration Processes*)
- new T&F instrument calibration services (*Validation and Testing*)

OBJECTIVE 3: technology transfer

- web based information (*Web Site*)

OBJECTIVE 4: international time comparisons

- geodetic GPS and GLONASS time transfer (*Modelling Techniques*)
- Two-Way Satellite Time & Frequency Transfer (*Modelling Techniques*)

OBJECTIVE 5: developing new time transfer methods for the UK

- GPS Disciplined Oscillators as 'traceable' T&F standards interface (*Metrology Software Development*)
- Developing a new GPS common-view instrument interface (*Metrology Software Development*)

In addition, this report covers NPL's work on the caesium fountain, currently part of the Foundation programme but related to the T&F programme.

3 Modelling Techniques

3.1 Methods for Modelling Measurement Data

3.1.1 Types of data

There are three categories of measurement data sets:

1. discrete measurement data, which means:
   a) data obtained by sampling a discrete variable: e.g., a variable that may take only integer values such as in counting processes, and
   b) data obtained by sampling a continuous variable.
2. continuous measurement signal, which means an analogue signal prior to any analogue to digital conversion.
3. hybrid measurement data composed of both discrete and continuous data sets.

In the T&F programme, much of the data collected relate to continuous variables (such as satellite position, phase differences and, of course, time), but are generally dealt with in a discrete form.

3.1.2 Modelling

3.1.2.1 Types of model

There are three categories of model:

1. discrete models in which the outputs of the measurement system are related to measurements of its inputs by a system of algebraic equations;
2. continuous models in which the outputs of the measurement system are related to measurements of its inputs by a system of differential equations;
3. hybrid models in which the outputs of the measurement system are related to measurements of its inputs by a system composed of both algebraic and differential equations.

It is appropriate to distinguish here between the nature of the model and the approach to solving the model (which for a continuous model typically also involves solving algebraic equations).

Given infinite precision arithmetic, the set of equations derived from a discrete model can be solved exactly. This is not the case for a continuous model which typically requires approximations to be made, for example, in terms of domain discretisation.

3.1.2.2 Models used in the T&F programme

There are a wide variety of models used in the T&F programme, ranging in physical scale from the atomic level (in atomic frequency standards) to global models and then to the Universe (for celestial reference frames used ultimately in defining time epochs). It would be a major undertaking to provide a comprehensive list of all the models used here and so, instead, five representative examples (a to e) are briefly described below. It is hoped that they will provide a flavour of the work undertaken in the programme and of the SSfM issues involved in that work.

a) The caesium fountain

The caesium fountain is a new form of primary frequency standard which has the potential to provide a substantial improvement in performance over that of existing standards. The innovation in the ‘caesium fountain’ compared with traditional ‘caesium beam’ standards is that the evaporated atoms are cooled down using lasers. The atoms then move more slowly so that longer measurement times and improved resolution are possible. The theory behind the caesium fountain is adequately understood, so there has been no need to model the basic physics (apart perhaps from the microwave cavity). No statistical modelling aspects have been addressed yet, but there may be scope in a later programme. However, recent CCTF recommendations highlight the need for greater clarity in the way that uncertainty is determined and expressed for measurements involving primary frequency standards (see CCTF Recommendations S2 and S3, April 1999). In particular, there is a need explicitly to state the method used in calculating an uncertainty associated with time series data. Some work will be needed in this area as the NPL caesium fountain moves from a development to an operational phase.

b) TWSTFT

Two-Way Satellite Time and Frequency Transfer (TWSTFT) is a high precision method of time and frequency transfer used principally by primary timing laboratories for the intercomparison of atomic time scales. TWSTFT differs from other methods of satellite time transfer in that signals are both transmitted to, and received from, the satellite. This has the advantage that many of the systematic errors present in receive-only time transfer methods are either eliminated or very substantially reduced.

A simple model of the TWSTFT process is used to account for the signal propagation delays at each stage in the communications chain, including delays in the two TWSTFT modems, the two satellite earth stations, the atmosphere (both up-link and down-link), and through the communications satellite. The measurements at each site lead to two algebraic equations involving the various signal propagation delays and the time differences recorded at each site. Subtracting one equation from the other eliminates those parameters that are poorly quantified, allowing the time difference between the clocks at each station to be calculated.

Unfortunately, the simple model is not perfect, as indicated experimentally by nanosecond level closing errors using data from three TWSTFT sites. In practice, the major limitations on the performance of a TWSTFT link is due to delay instabilities in the earth station instrumentation. As a result the delays in the transmit and receive parts of the satellite earth station do not cancel exactly. The delay instabilities depend on a number of interdependent parameters (temperature, signal power, multipath, etc) and so efforts to overcome these limitations rightly have focused on improved calibration schemes rather than more sophisticated earth station models. The one area where physical models have produced greater insight is in modelling the impact of multipath in the instrument cables on the time code correlation schemes (that part of the TWSTFT modem that measures the time differences between the local clock and the received time signal). There are other assumptions that are model dependent: the up-link and down-link to the communications satellite for instance are on different frequencies, and so the delays do not cancel exactly (although for the time being, the difference is too small to be of consequence to the TWSTFT time transfer results).

In practice, NPL makes regular TWSTFT comparisons three times per week with several other primary timing laboratories, located both in Europe and in North America. Programs written in Delphi handle data from the TWSTFT modems. After reduction (by applying a standard set of time and frequency statistics based on 2^{nd} order differences, and a cubic spline fit) and formatting, the data gathered at NPL are put on an FTP site and compared with that from the other laboratories. Statistical techniques are used to clarify when the data is limited by clock noise processes and when it is limited by noise in the communications link. The way that the TWSTFT sessions are scheduled means that the method produces unevenly spaced data sets and the additional errors introduced by interpolation schemes to produce evenly spaced data sets for statistical analysis have been studied and quantified. It is hoped that time transfer accuracies of a small fraction of a nanosecond will ultimately be achieved. It is intended to use TWSTFT to compare the caesium fountain clocks under development at NPL and at other national standards laboratories.

c) GPS common-view time transfer

NPL has for many years used the Global Positioning System (GPS) for time and frequency transfer, in order to compare the national time scale UTC(NPL) against other atomic time scales at primary timing laboratories. However the method used, the common view of GPS satellites using single-channel and single-frequency C/A code observations only, does not use all of the information available from the GPS, or take account of developments in geodesic GPS techniques.

NPL has started to investigate the use of geodesic quality GPS receivers for time transfer. These receivers record all of available code and phase variables, and offer the potential of substantially more precise time and frequency transfer than is available using the older common view receivers. It is hoped that the techniques will result in time and frequency transfers with measurement precision of tens of picoseconds (which would be sufficient to compare the new caesium fountain clocks being developed both at NPL and at other national standards laboratories). Such accuracies are possible in part because antenna positions can be fixed very accurately.

In the model for this system, six parameters relating to orbit are used and are relatively easy to handle. Ionopheric and tropospheric effects are dealt with by correlations but the latter is a problem area where more work is needed. The geodetic solution that enables the understanding of the physical processes (such as humidity) was modelled on a spreadsheet by NPL staff and developed into a Delphi program.

d) GPS Disciplined Oscillators

In 1997 NPL collected data from 15 GPS Disciplined Oscillators (GPSDO) with the aim of reporting on the feasibility of tracing the results back to UTC(NPL), the national timescale. The data are being analysed using standard time and frequency statistics, essentially Allan variances (2^{nd} order differences), to characterise the GPSDO frequency stability and 1^{st} order differences for accuracy. The later part of the analysis seeks to correlate diagnostic parameters from the GPSDOs with the time and frequency outputs. As an example, some GPSDOs showed anomalous transients - the frequency diverging from nominal in a clearly non-statistical manner, and then being steered back towards nominal. The transient effects were shown to be correlated with a change in the set of GPS satellites in view. This example shows that a simple generic model for the “normal” operation of the GPSDO components - that is GPS, the local oscillator and the disciplining processes - is being applied.

The work is near completion and results have already been presented to UKAS. One laboratory has gained UKAS accreditation for a frequency traceability service on the basis of the knowledge gained from the NPL GPSDO study. A guidance document is in preparation but is waiting on the statistical analysis referred to above and work on error budgets for GPS before it can be finalised.

A service to calibrate and characterise disciplined oscillators is planned and consequentially some work will be needed to model and quantify the uncertainties associated with such instruments.

e) Time scale algorithms

Statistical models are being developed to optimise the output from an ensemble of atomic clocks. The stability of each of the individual clocks in the ensemble can be determined from comparing one against another, and that information used to compute a more stable time scale than would be possible from a single clock alone. Such an algorithm needs to be optimised for the intended application: an algorithm delivering very good short term stability may perform poorly in terms of long term accuracy for instance. There are plans to extend this work to more geographically dispersed ensembles (the global UTC system, or a national time service are possible examples) where the stability of the clock comparisons need to be taken into account.

3.2 Uncertainties and Statistical Modelling

The NPL Time Section is about to offer new measurement services so the to the Guide to the Expression of Uncertainties of Measurement (GUM [2]) is an issue at this time. In the future, as their clock characterisation services develop, there may be problems with GUM since there is already a body of work describing how to handle uncertainties in the Allan Variance (used to characterise frequency instabilities) for various noise types. The development of new measurement services will require them to look to GUM more closely, to ensure compatibility is maintained - or if not, that test reports make explicit why and where differences occur.

In terms of standard Allan Variance, there is a solid body of work that quantifies the uncertainties and states explicit confidence limits. Confidence limits are often other than 95% - both 1 sigma and 3 sigma uncertainties are most commonly used.

Key staff have received relevant training from NIST and UKAS.

3.3 Visual Modelling and Data Visualisation

Visual modelling and data visualisation are currently used in the T&F programme, typically in the form of simple graphs generated from Excel spreadsheets and Delphi programmes. Efforts are being made to extend these techniques in the time transfer area, where programs are being developed to aid the visual comparison of data both from different time transfer methods and from time transfer links to different laboratories.

3.4 Data Fusion

It is hoped that combining time and frequency data from GLONASS (Global Space Navigation System, a Russian satellite based navigation system), GPS and the Two-Way Satellite Time Transfer method will result in lower uncertainties associated with time and frequency transfer. This would appear to be a perfect application for data fusion as they involve combining multi-parameter measurements to obtain a single solution.

Another promising application lies in the work on timescale algorithms outlined in e) *Timescale Algorithms* above.

4 Validation and Testing

4.1 Spreadsheets and Other Mathematical Software Packages

4.1.1 'Off the shelf' software

Origin is used for data analysis in the development of the caesium fountain, but this represents a small fraction of the work on data analysis undertaken in the T&F programme as whole. Instead, spreadsheets and in-house software are used for the majority of the work.

4.1.2 Spreadsheets

Spreadsheets (Excel) are used throughout the T&F programme, either to provide a ready graphical view of data, or for simple data analysis exercises. Macros are commonly used for tasks that are repeated routinely, while in-house software is used for more complex (or routine) data manipulation exercises.

4.1.3 Awareness of limitations

There is awareness of the potential limitations in spreadsheets arising from inaccurate or unstable numerical algorithms, but only limited knowledge of specific problematic functions.

4.1.4 Testing and validation

The initial tests on a new software package are usually limited to a top-level user assessment of whether the package is fit for purpose. Simple validation tests will be carried out as part of that process, but systematic testing and validation is not. In practice, tests are carried out throughout the working life of any software package, but with the focus being placed on the applications developed within the package, rather than on the package itself.

There is scope for any future SSfM programme to provide guidance to the T&F programme on 'best-practice' for testing and validation of new software packages. Areas where guidance would be welcome are:

- practical approaches to testing and validation,
- known test results (to save repeating tests unnecessarily),
- a cost/benefit analysis comparing the benefits of initial package testing against continuous application testing.

4.1.5 Traceability

In the NPL Time Section, which carries out the majority of work in the T&F programme, each individual developing software maintains his or her own archive of that software. However, the intention is that a version control system should be used for managing software development in future. One such system has been tested already, but was rejected because weaknesses when used on a network basis. An alternative is being identified for a second trial.

Some software development has been carried out by the Centre for Information Systems Engineering on behalf of Time Section. Here the widely used RCS (Revision Control System) is generally preferred, and in particular a version known as SC-RCS for PC systems

4.2 Model Validation

Models are used throughout the T&F programme. Some are part of the global infrastructure and are used in fields such as geodesy, satellite navigation, and telecommunications. They can be viewed as uncontroversial, on the basis that their accuracy is measured and quantified by a number of different organisations. Some general examples are listed below:

- atmospheric models
- geodetic reference frames
- celestial reference frames
- models for the Earth's gravity field
- models for satellite orbits
- models for radio wave propagation, from 10 kHz to Terahertz

Other models in use are specific to a manufacturer, or institution, and hence need more careful assessment. Some examples here would be:

- GPS satellite simulator
- MSF simulator
- GPS Disciplined Oscillator model

Yet other models are actively developed by the Time Community, and hence fall into the category of model development rather than purely validation. Some examples here would be:

- time scale algorithms
- geodetic GPS/GLONASS common-view time transfer.
- Two-Way Satellite Time Transfer

In the latter examples, software has been developed elsewhere (e.g. 'GIPSY' developed at the Jet Propulsion Laboratory and 'Bernese' distributed by the University of Berne, for geodetic time transfer) but parallel work is being carried out within the NMS Time & Frequency Programme to establish greater confidence in the results derived from the generic models.

In all of the cases listed above, the outputs of models are compared for internal self-consistency and against real-world measurements. Three specific examples are testing a GPS satellite simulator on a well-characterised GPS receiver (a confidence building measure rather than a full validation), comparing time scale algorithms against real clocks using statistical measures, or, comparing one time transfer method against another to identify the presence of systematic errors.

4.3 Measurement System Validation

4.3.1 Embedded software

Embedded software is found in many key measurement systems used in the T&F programme, in equipment such as caesium clocks, hydrogen maser frequency standards, GPS timing receivers, TRUETIME telephone time service, modems, time scale generators, and counter timers. There is no detailed validation undertaken for all the units. However, confidence in the overall integrity of the systems is improved by self-consistency checks of the various outputs.

There are special concerns in one particular project to identify traceability routes for certain commercial GPS timing receivers. The preferred route would be to validate the code embedded in the receivers. However, this is proving difficult because of the commercial sensitivities involved in the release of the software. Hence the alternative route of testing the GPS timing receiver inputs and outputs is having to be employed instead.

4.3.2 Reference data

Good reference data sets are valuable here as benchmarks for ‘normal’ time equipment/system operation, where ‘normal’ may also include common fault mechanisms. Examples include long-term data records for specific atomic clocks (currently used in work on time scale algorithms) and GPS navigation message records (useful in providing realistic input data to GPSDO models as part of traceability studies).

4.3.3 Supplier guarantees

It is possible to obtain statements on Y2K and GPS week number rollover for the equipment and systems used in the programme.

4.3.4 Supplier validation of embedded software

The NPL Time Section, as a rule, has to rely on the claims of manufacturers that embedded software has been adequately tested against supplier specifications.

Within NPL, software supplied by one part of NPL to another will normally be produced to a software quality standard forming part of the NPL quality system. This ensures that adequate testing is performed before the software is put into use.

4.4 Validation of Simulated Instruments

A software-based model of a GPSDO has been constructed, to explore GPSDO operations more quickly than would be possible using purely experimental techniques. While the disciplining algorithms from commercial units are not available for study, the broad principles of operation can be simulated and related to common effects in real-world units. In addition, a commercial GPS simulator is used, with tests carried out on known GPS receivers to gain confidence in the simulator behaviour.

5 Metrology Software Development Techniques

Some Pascal programs exist in the NPL Time Section but the main programming language used is Delphi.

Software is developed according to NPL’s procedures which, for programs that are to be used in a service, dictates a traditional waterfall model. There are NPL Time Section programs in use that were developed before software engineering procedures were in place (for example, code relevant to the MSF service has been running since 1970). Some of these programs are being re-written to take advantage of modern platforms, enhance the user interface and generally improve the quality.

The software for the caesium fountain is currently at the prototype stage, it will need re-engineering before release of data to the International community. LabVIEW is used for the instrumentation and Origin for data analysis.

Most other applications developed in the programme make use of Excel, Access and Visual Basic and are very simple, helping in the production of reports and statistical analysis.

5.1 Software development methods

Software development is carried out either in-house or by external contractors. In-house development tends to occur where suitable expertise exists and can be utilised, where the software development is integral to a better understanding of a physical process or where projects are relatively small (typically a few man-months).

The development methodologies employed have traditionally ranged from the rough and ready construction, aimed at getting some working code in order to demonstrate feasibility, to the more formal approaches of a professional software house. The software development process used needs to reflect the risk associated with the software; so, for example, software used in prototyping is often written before the design documentation, whereas software used in the operation of a service needs to be developed using good software engineering practices.

However, much of the software developed within the programme is directed towards improving the scientist's knowledge of the physical processes under study. Such software development tends to be carried out in an iterative fashion, with more rigid software development models being employed at a later stage when the improved knowledge is being applied to an operational system. One specific example of this iterative knowledge gaining process would be the current development of geodetic time transfer software. The improved knowledge enables staff from the NPL Time Section to make a more critical analysis of two other widely used (but less transparent) geodetic software packages.

5.1.1 Software quality

5.1.1.1 Quality systems

NPL is certified to ISO 9001 plus TickIT, any software NPL sells or uses in a service is properly engineered and produced in accordance with documented procedures

5.1.1.2 Reliability records

Records are kept in individuals' lab books, but there is no Section-wide monitoring or control in place at this stage in the NPL Time Section.

5.1.1.3 Reliability

The NPL Time Section relies on a combination internal self-consistency checks and external checks against other timing organisations to detect significant errors in its outputs.

5.1.2 Management issues

5.1.2.1 Maintenance

Older software developed in-house can be expensive to maintain since much is poorly documented and in many cases the authors have left the organisation.

5.1.2.2 Development costs

In-house software development centres around spreadsheet macros, small applications using the Microsoft Office suite, and Delphi programs. 90% of the NPL Time Section development work involves learning about the capabilities of the equipment, and so the software is developed in an iterative manner for necessary reasons. On that basis, it is felt to be cost effective to have key development staff carrying out the programming tasks.

5.1.2.3 Problems

For software developed in-house, the biggest problem is maintainability in the face of advancing technology. Some older applications need re-writing as the development tools are no longer supported. Having decided to develop their own software, training is an issue - an upgrade to a new platform or language can slow down T&F work substantially.

5.1.2.4 Quality attributes

The most important software quality attribute in T&F is probably reliability. Several very public services (such as MSF) rely on software. Clearly other factors have an impact as well. The NPL Time Section find that they have scientists/programmers who are working on related problems and sharing code - hence usability and maintainability are becoming more important.

5.1.2.5 Risks

Failure of software in use results in down time and the potential for embarrassment for the laboratory. Data integrity failures may cause problems. The risk of software errors causing incorrect results to be reported to customers is also serious, for example the production of Measurement Bulletin used for national frequency traceability, time data to BIPM, etc (although there have been no actual software errors affecting customers to date).

On the other hand, the risks associated with in-house software developed for research and prototyping purposes are quite low since such systems are heavily validated as part of the development process.

5.1.3 Technical issues for software developers

5.1.3.1 Development methods

Two distinct development methods are employed on the programme. In one method, an iterative approach is used where the software development is part of the learning process (where a meaningful design specification cannot be written because of insufficient knowledge of the physical system under study). In the other method, used for more formal operational systems, developers use the traditional waterfall model approach where the process is viewed as a series of stages such as requirements capture, software design, implementation and test.

5.1.3.2 Software testing methods

The correctness of software is checked by each of the following methods:

- checking the results by using another instrument,
- checking the results by hand,
- using a mathematical tool or spreadsheet, etc.

5.1.3.3 Development problems

No development problems have been identified in the NPL Time Section at the present time.

5.1.3.4 NPL Measurement Good Practice Guide 5, Software in Scientific Instruments

NPL Measurement Good Practice Guide 5 is widely available within NPL and has been extensively distributed outside through Competing Precisely events and now through the SSfM Club. Feedback on its use has been received, but not yet from those active in T&F.

There is no evidence that suppliers in this area use the guide, although there is some awareness of the issues concerned as the SSfM programme has been presented at T&F User Club meeting.

5.2 Software reuse

5.2.1 Management issues

5.2.1.1 Importance

Software reuse is seen as an important means of reducing software maintenance costs. As an example of this in practice, the NPL Time Section decided to move to the Delphi language just over a year ago because Pascal was no longer supported by Borland. One of the prime reasons for choosing Delphi was that existing Pascal code could then be reused.

5.2.1.2 Mixed language programming

Mixed language programming tends not to be used for in-house projects.

5.2.1.3 Responsibility

The details of software reuse and mixed language programming tend to be left to the development teams or their suppliers.

5.2.1.4 Legacy software

Legacy software is generally not a problem, although there have been cases where support is no longer available from the suppliers.

5.2.1.5 Year 2000

The Year 2000 (Y2K) problem has been recognised for some time. NPL has a task group working on this issue, testing every piece of appropriate equipment. It is not yet known what impact Y2K will have on the delivery of NMS milestones since, in part, it depends on how the relevant suppliers and subcontractors will be affected.

GPS systems are potentially as susceptible to the Y2K problem as any other computer-based systems, and unfortunately there is an additional problem that may have afflicted some receivers in August 1999. Counters in the receiver rolled over at midnight 21^{st} August 1999 and, unless care was taken, the date may have been reset to 6 January 1980. The problem is well known and does not seem to have caused many serious difficulties.

5.2.2 Technical issues for software developers

The main issue concerns the requirement for a development methodology that allows iterative evolution of software as the specification is developing, followed by a minimum of effort to turn the resulting product into a well engineered item.

5.3 Virtual Instruments

Virtual instruments are not widely used in the T&F programme. However, there are isolated or related examples. LabVIEW is used in the development of the caesium fountain, a GPS satellite simulator is used for some experiments, and a software model of a GPS Disciplined Oscillator has been developed as a part of a wider GPSDO study.

6 Support for Measurement and Calibration Processes

6.1 Automation of Measurement and Calibration Processes

New calibration services are being established and this may lead to a requirement for a LIMS, hence guidance on selection of LIMS would be timely.

6.2 Format Standards for Measurement Data

No requirements for specific data formats have been identified for any of the new T&F calibration services. However, standard data formats are well established for routinely communicating time information, be it MSF, GPS or TWSTFT.

7 Suggestions for Future Activities

7.1 Expected Benefits of the SSfM Programme

The areas of the SSfM programme which are most likely to benefit the T&F programme are modelling techniques, model validation, visual modelling (possibly), software development methodology and guidance on LIMS. Some thought is being given to the dissemination of data through the web, so the SSfM tasks related to Java and the web are also relevant. Additionally, good practice guidelines on testing and validation of 3rd party software would be welcome.

7.2 Case Studies and Feasibility Studies

The GPS time transfer work involves aspects both of modelling and data fusion. For the former, the problem is to understand the various error sources and their effects, and using this knowledge to refine and develop models for the GPS system until the required accuracies are achieved. It might constitute a data fusion application because the GPS system returns a number of measurements (of different accuracies) from which a single result is to be determined.

The problem of visualising large amounts of data could provide an interesting example for visual modelling and data visualisation.

The clock algorithms work requires the combination of the "outputs" of a number of clock comparisons or time transfer methods into a single time scale where there is an expected correlation between the individual "outputs". This analysis of correlated data (which is pertinent both to the modelling and uncertainty projects) could be viewed also as a data fusion problem.

7.3 Future SSfM Topics

There are a number of time and frequency metrics used to quantify the stability of time and frequency signals. In the Time Metrology community, the Allan variance is widely used, while in the telecommunications world, concepts such as “jitter” and “wander” are more common. There may be value in looking at such statistical measures, to identify ways of incorporating these terms into future versions of the GUM.

A second, as yet unexplored area, is the validation of embedded software in GPS timing receivers. At present, there is little explicit validation of the base data or algorithms used in such equipment.

7.4 Future T&F Programme Topics

The items listed in section 7.3 might develop into topics for future T&F programme, but it is still too early to say whether they would be priority topics at this stage.

8 Summary

The main changes since the initial restricted edition of this report are:

- An outline of some of the SSfM relevant T&F programme activities.
- More details of modelling applications.
- More detail on testing and validation.
- An update on software development methods.

New parts of the T&F programme draw on SSfM ideas, notably:

- The algorithms work (data fusion and data visualisation).
- New measurement services (GUM related developments).

Other topics identified as increasingly relevant are:

- Confidence levels other than 95%.
- Best practice for testing and validation.
- Software reuse.
- Iterative software development methods.

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Appendix 1: Glossary of Abbreviations

Abbreviation	Expansion
BIPM	Bureau International des Poids et Mesures
CCTF	Consultative Committee for Time and Frequency
CETM	Centre for Electromagnetic and Time Metrology
GIPSY	GPS-Inferred Positioning System
GLONASS	Global Space Navigation System
GPS	Global Positioning System
GPS DO	GPS Disciplined Oscillator
ISO	International Organization for Standardization
LIMS	Laboratory Information Management System
MSF	3 letter call sign for the time dissemination service broadcast from Rugby
NMS	National Measurement System
PC	Personal Computer
RCS	Revision Control System
SSfM	Software Support For Metrology
T&F	Time and Frequency
TWSTFT	Two-Way Satellite Time and Frequency Transfer
UKAS	United Kingdom Accreditation Service
UTC(NPL)	Universal Co-ordinated Time, as realised at NPL on behalf of the UK.
Y2K	Year 2000

Appendix 2: Bibliography

1. Rayner, D., *Initial Report on Status of Software and Mathematics in each Metrology Area,* NPL Report CISE 18/99, February 1999.
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