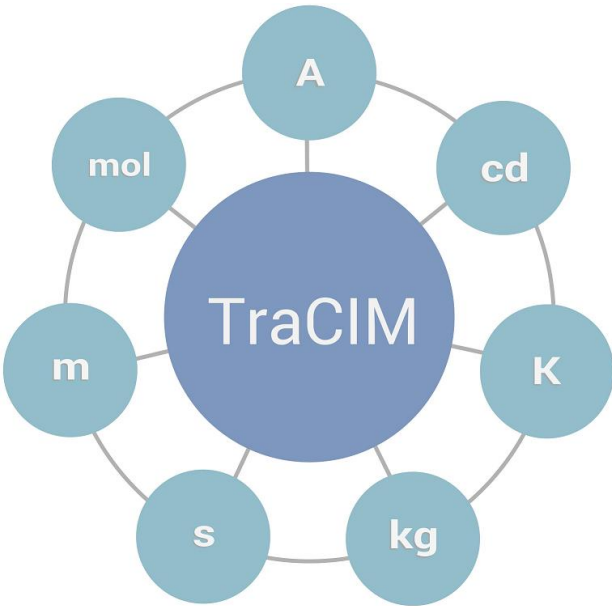


**Guidance on the use of the TraCIM system at NPL to undertake verification of mathematical functions using standalone TraCIM clients**

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## Summary

This document constitutes Deliverable 1 of the European Metrology Programme for Innovation and Research (EMPIR) Support for Impact Project (SIP) 15SIP06 “Validation of software development and analysis tools using TraCIM” (short name “ValTraC”). The document provides general guidance for the developers of mathematical software tools on the use of the TraCIM system to undertake verification of mathematical functions using standalone TraCIM clients.

## 1. Introduction

The European Metrology Research Programme (EMRP) Joint Research Project (JRP) NEW06 “Traceability for Computationally-Intensive Metrology” (short name “TraCIM”), 2012–2015, developed a framework for the online verification of mathematical software used within metrology. The framework comprises three elements: specifications of computational aims; reference pairs (comprising reference input and output data); and an information communications technology (ICT) infrastructure. The framework allows National Measurement Institutes (NMIs) involved in the JRP to provide “TraCIM software verification services” for implementations of mathematical calculations.

The ICT infrastructure, referred to as the “TraCIM system”, allows communication, via the internet, between the user of a TraCIM software verification service (referred to as a “service user”) and the provider of the service (the “service provider”). For a particular calculation, the TraCIM system comprises the “TraCIM server”, hosted by an NMI, and a “TraCIM client”, a software module implemented by the service user to facilitate communication with the TraCIM server. The TraCIM client may be classified as “standalone” or “integrated” depending on the ability of the software environment within which the software under test is running to communicate via the internet.

This document provides generic guidance on the use of TraCIM software verification services provided by the National Physical Laboratory (NPL) and has a particular focus on standalone TraCIM clients. The document is organised as follows. Section 2 gives an overview of the TraCIM approach to the verification of mathematical software and describes the main components of the framework that form the basis of a TraCIM software verification service. Section 3 describes the steps in the use of a TraCIM software verification service. Section 4 provides general advice for a service user on the development of a TraCIM client, while section 5 contains specific advice relating to standalone TraCIM clients.

For each NPL TraCIM software verification service, specific guidance on the use of the service is provided in a user manual for that service. Note also that a separate document provides generic guidance on the use of TraCIM software verification services provided by NPL and has a particular focus on integrated TraCIM clients.

## 2. The TraCIM approach to the verification of mathematical software

The TraCIM project developed a framework that allows verification of mathematical software (that is, software that implements mathematical calculations) used within metrology to be undertaken via the internet. The framework comprises the following elements:

1. Specifications of computational aims (section 2.1).
2. Reference pairs (section 2.2).
3. An information communications technology (ICT) infrastructure (section 2.3).

## 2.1 Specification of computational aim

A specification of a computational aim (often referred to simply as “a computational aim”) is a document that provides a complete and unambiguous description of the calculation or set of calculations to be undertaken. The computational aim informs both the developer of software that implements the computational aim and the tester of that software. The specification of the computational aim covers only what is to be calculated and need not provide details on how a calculation should be implemented. Often, there is more than one algorithm that can be implemented to undertake a calculation, and the choice of algorithm is principally of concern only to the software developer.

As part of the TraCIM JRP:

- A procedure was developed that describes how a computational aim is stored as a Portable Document Format (PDF) file. The computational aim comprises information contained in a number of fields. For example, the “Mathematical model” field provides a statement of the problem to be solved or task to be undertaken, and details the mathematical relationship between parameters described in the fields “Input parameters” and “Output parameters”.
- The “Computational Aims Database” [1] was developed to allow computational aims, in the PDF format described above, to be stored and retrieved. The database was populated with computational aims for a number of common metrology applications.

## 2.2 Reference pairs

Reference pairs are commonly used in the verification of mathematical software. A single reference pair comprises reference data and corresponding reference results. Simplistically, a reference pair can be thought of as comprising data for which the corresponding results are “known” with an assured quality.

Reference pairs are used as follows. The software under test is applied to reference data to obtain corresponding test results. The test results are then compared, in an appropriate way, with the corresponding reference results, allowing an assessment to be made of the numerical performance of the software for that reference pair (see Figure 1).

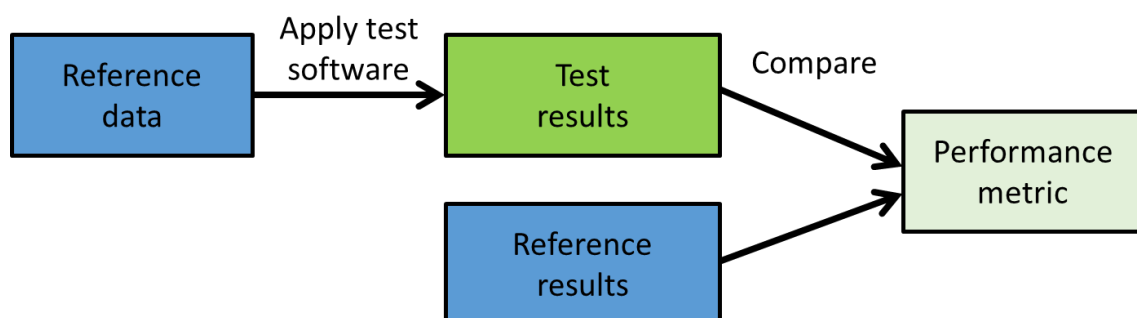


Figure 1: Determination of a performance metric using a single reference pair.

Repeating this process for a large number of reference pairs allows an overall assessment to be made of the performance of the software (see Figure 2).

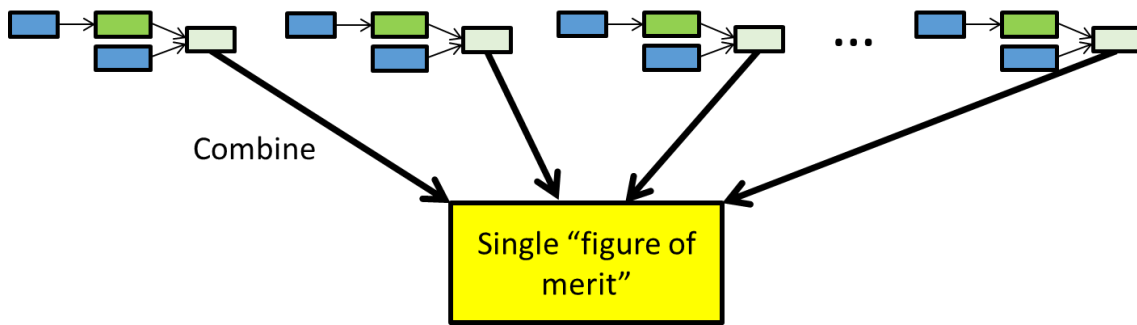


Figure 2: Assessing the performance of software using multiple reference pairs.

As part of the TraCIM JRP:

- Software to generate reference pairs was developed for a number of computational aims of particular interest within metrology.

### 2.3 ICT infrastructure

The TraCIM system, the ICT infrastructure developed during the TraCIM project, forms the basis of TraCIM software verification services. The TraCIM system allows communication between the service provider and the service user using internet services. The TraCIM system comprises two main elements:

- The "TraCIM server", the core software module that manages all of the operating data and controls the flow of data to other modules. The TraCIM server is hosted by the service provider. Each service requires the development of an "expert extension", a software module that is incorporated into the TraCIM server and implements all the operations relating to that service.
- The "TraCIM client", a software module that allows the service user to communicate with the TraCIM server. The TraCIM client runs on the site of the service user and may be implemented in the programming language of choice of the service user.

Figure 3 illustrates the main elements of the TraCIM system.

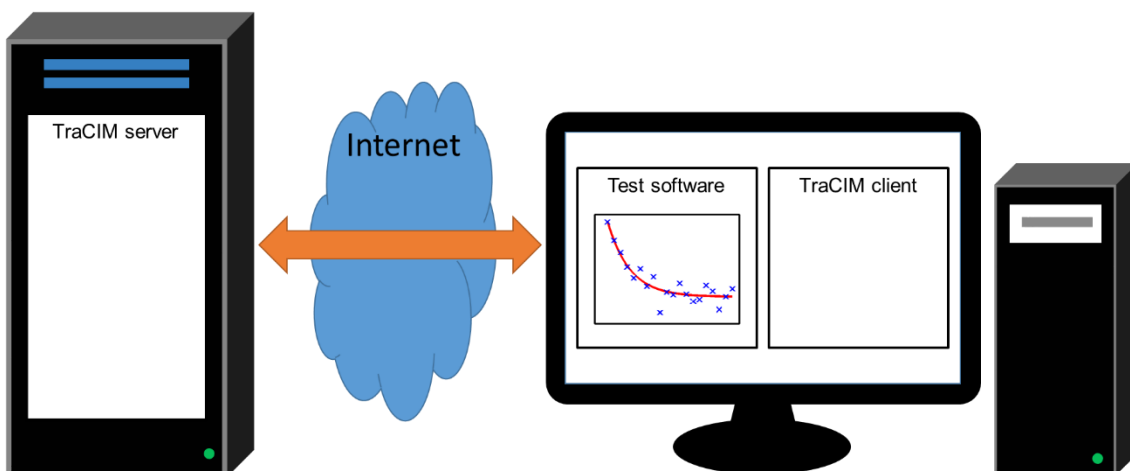


Figure 3: Elements of the TraCIM system.

Two distinct types of TraCIM client exist:

- “Standalone” TraCIM clients – in some cases, the software environment within which the software under test is running is not able to communicate directly with the TraCIM server. A TraCIM client that runs independently of that software environment, and within a software environment that does permit communication with the TraCIM server, must be implemented.
- “Integrated” TraCIM clients – in other cases, the software environment within which the software under test is running is capable of communicating directly with the TraCIM server. A TraCIM client may then be implemented within that software environment.

In Figure 3, a standalone TraCIM client is illustrated.

### 3. Using a verification service

Figure 4 shows the main steps in the use of a software verification service. The central dotted line represents the physical separation of the service user and the service provider. Arrows indicate the direction of communication between service user and service provider. Bold upper case is used to indicate communication for which the service user is required to use a TraCIM client. Rectangular boxes indicate tasks to be undertaken that do not require communication between service user and service provider.

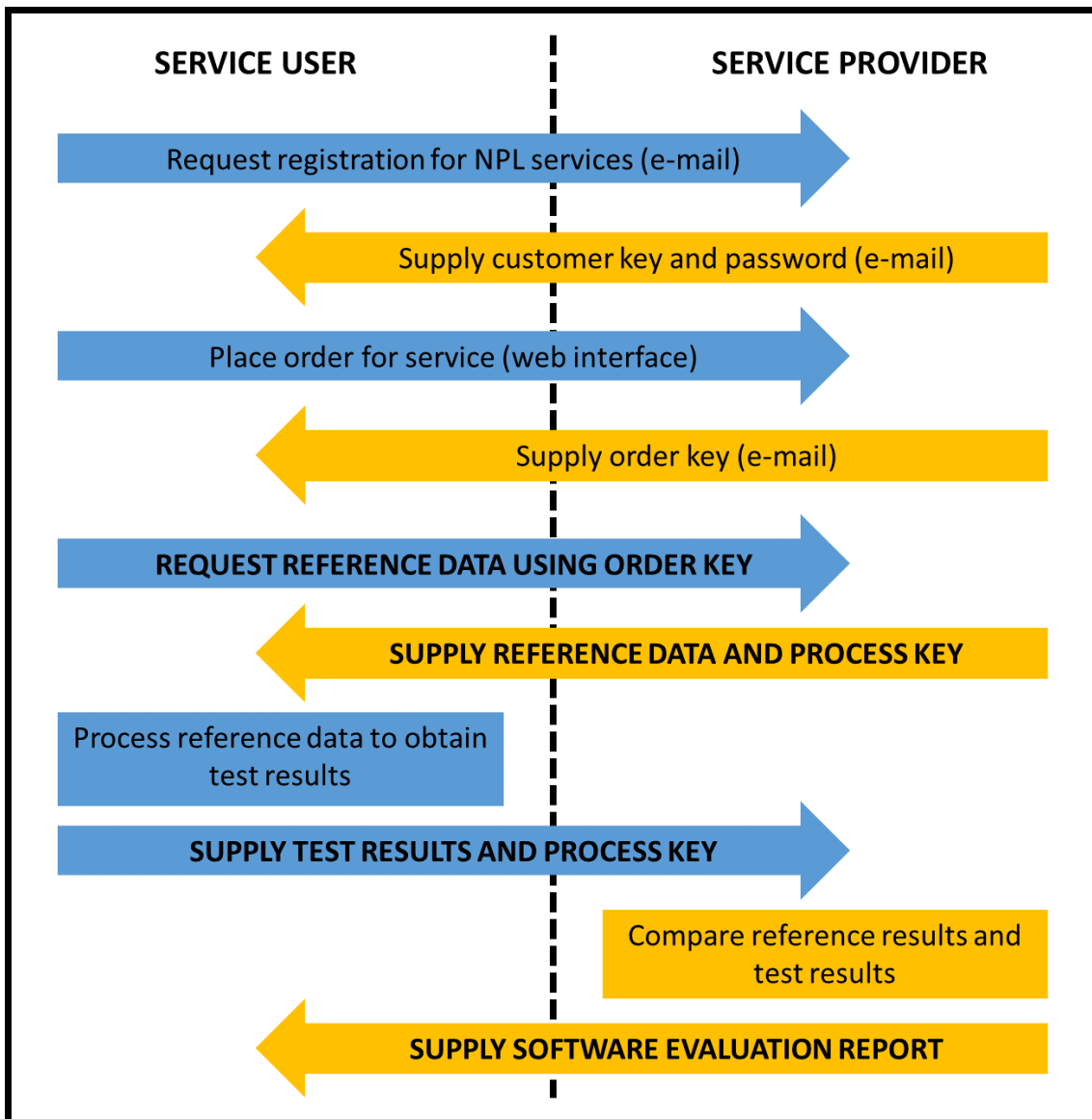


Figure 4: The main steps in the use of a software verification service.

### 3.1 Request registration for NPL services

To request registration to use NPL TraCIM software verification services, an e-mail including the word “Registration” in the subject field and containing the following information:

- Company name,
- Address (Number and street name, Town/City, County/State/Province, Postal code, Country), and
- Details of individual service user (Name, Title, E-mail address, Phone number),

should be sent to [support.tracim@npl.co.uk](mailto:support.tracim@npl.co.uk).

### 3.2 Supply customer key and password

Upon successful registration, the service user will be sent an e-mail containing a “customer key” (username) and initial password. It is recommended that the service user immediately change the password. To do so:

- Navigate to the NPL TraCIM webshop <https://tracim.npl.co.uk>,
- Login using the provided customer key and password,
- Click on **My Account** in the main menu bar,
- Click on the **Change password** button, and
- Enter the old (initial) password and the new password in the text boxes provided and press the **Submit** button. Note that passwords must contain at least 8 characters.

### 3.3 Place order for service

To place an order for a particular service:

- Navigate to the NPL TraCIM webshop <https://tracim.npl.co.uk>,
- Login using customer key and password,
- Click on **Order** in the main menu bar,
- Select a metrology domain from the dropdown menu,
- Select a specific test (calculation) from the dropdown menu for that metrology domain, and
- Click on the **Order public test** button.

### 3.4 Supply order key

Upon successful placement of an order, the service user will be sent two e-mails:

1. The first e-mail provides confirmation that the order was received, and
2. The second e-mail provides confirmation that the order has been activated and contains an order key. The order key contains 16 alphanumeric characters and is used to request reference data.

### 3.5 Request reference data using order key

The TraCIM client must be used to send to the TraCIM server a request for reference data. More information is supplied in the manual for each calculation.

### 3.6 Supply reference data and process key

The TraCIM client must be used to receive from the TraCIM server reference data and an accompanying process key. The process key contains 16 alphanumeric characters and is used when submitting test results. More information is supplied in the manual for each calculation.



### 3.7 Supply test results and process key

The TraCIM client must be used to submit to the TraCIM server test results and the corresponding process key. More information is supplied in the manual for each calculation.

### 3.8 Supply software evaluation report

The TraCIM client can be used to receive from the TraCIM server the software evaluation report encoded in “base64” format. More information is supplied in the manual for each calculation.

Alternatively, a PDF version of the software evaluation report can be obtained as follows:

- Navigate to the NPL TraCIM webshop <https://tracim.npl.co.uk>,
- Login using customer key and password,
- Click on **My Account** in the main menu bar,
- Click on the **My Orders** icon,
- For the order key (listed in the column labelled “key”) of interest, click on “View processes”,
- For the process key (listed in the column labelled “Process key”) of interest, click on “Details”,
- Click on “Get PDF for test”,
- To view the software evaluation report in a new browser tab, click on “PDF-Link [new window]”, and
- To save the software evaluation in PDF format, right-click on “PDF-Link [new window]”, and follow the steps to save. In most browsers, the default name of the software evaluation report is the process key with extension pdf.

The first page of the software evaluation report contains the following information:

- The name of the computational aim,
- The identifier for the computational aim in the Computational Aims Database,
- The details of the software under test,
- The details of the verification being undertaken (the output parameters being tested, and the tolerances for those parameters supplied by the service user),
- The date of the verification,
- The process key,
- The number of pages in the report, and
- The overall test result (“PASS” or “FAIL”).

Subsequent pages of the software evaluation report provide a summary of the verification undertaken, full details of the verification procedure, and the outcome of the verification. If the overall verification result is “FAIL”, the software evaluation report lists the individual reference data set(s) for which the software under test failed.

## 4. Development of a TraCIM client

The TraCIM client must allow the service user to:

- Submit a request for reference data to the TraCIM server,
- Receive reference data from the TraCIM server,
- Submit test results to the TraCIM server, and
- Receive the software evaluation report from the TraCIM server, via the internet.

Submitting information to the TraCIM server requires the TraCIM client to use a Hypertext Transfer Protocol Secure (HTTPS) connection to send and receive content in the form of character strings containing messages in Extensible Markup Language (XML) format. Each HTTPS connection is created from a particular Uniform Resource Locator (URL).

On opening a connection, the following configurations must be selected:

- Enable input and output operations for the connection.
- Set the request method “POST” (request comprising input and output).
- Set the connection property “content-Type” to “application/xml”.
- Set the connection property “accept” to “application/xml”.
- Set the connection property “content-length” to the number of characters of the content that is sent to the TraCIM system.

#### 4.1 Request reference data

To request reference data, the URL of the HTTPS connection for the POST request is

[https://tracim.npl.co.uk/tracim/api/order/CALCULATION\\_ORDER\\_KEY/test](https://tracim.npl.co.uk/tracim/api/order/CALCULATION_ORDER_KEY/test),

where CALCULATION\_ORDER\_KEY is the order key supplied to the service user. Following the creation and configuration of a connection as described above, the TraCIM client has to send the request message to the TraCIM server.

If the service user submits an invalid order key, the TraCIM server will supply an error message.

#### 4.2 Receive reference data

On receipt of the request for reference data, the TraCIM server will supply, within an XML message, reference data to the TraCIM client. The XML message comprises the following elements:

- The order element comprises the order key, the date of generation of the reference data, and the expiration date for the reference data, that is, the deadline by which test results should be supplied to the TraCIM server,
- The process element comprises the process key associated with the test results, and
- The reference data element comprises a number of sets of reference data to be processed by the software under test.

The user manual for each calculation describes the content of each element.

#### 4.3 Submit test results

The TraCIM client must submit test results, within an XML message, to the TraCIM server. The XML message comprises the following elements:

- The results package element,
- Tolerance elements – each element contains, for a particular output parameter, a tolerance value to be used when comparing reference and test results, and
- Software information elements – each element contains a particular piece of information (Name, Version, Revision, Vendor and Details) about the software under test.

The user manual for each calculation describes the content of each element.

To submit test results, the URL of the HTTPS connection of the POST request is

[https://tracim.npl.co.uk/tracim/api/test/CALCULATION\\_PROCESS\\_KEY](https://tracim.npl.co.uk/tracim/api/test/CALCULATION_PROCESS_KEY),

where CALCULATION\_PROCESS\_KEY is the process key supplied by the TraCIM server in response to the request for reference data.

If the service user submits an invalid XML file, the TraCIM server will supply an error message.

#### 4.4 Receive software evaluation report

On receipt of test results, if the test results are in the correct format, the TraCIM server will supply, within an XML message, the software evaluation report. The XML message comprises an element that contains the following sub-elements:

- The passed element indicates if all tests have passed.
- The report element contains a character string that summarises the outcome of the verification process.
- The PDF report element that contains the software evaluation report encoded in “base64” format.

### 5. Considerations for a standalone TraCIM client

A standalone TraCIM client must be used when the software environment within which the software under test is running is not able to communicate directly with the TraCIM server. For example, communication using internet services may not be possible within the software environment. In such a case, the service user is required to implement a standalone TraCIM client running within a (different) software environment that allows communication using internet services **and** XML messages to be read and written.

One approach implemented by a standalone TraCIM client involves the following steps:

1. The TraCIM client requests reference data from the TraCIM server.
2. On receipt of the XML message containing the reference data, the TraCIM client extracts the reference data into ASCII reference data files, one file for each reference data set.
3. For each ASCII reference data file, the software under test is applied to the reference data therein and the test results are written to a corresponding ASCII test results file.
4. The TraCIM client loads the contents of the ASCII test results files and writes them, together with tolerance values and software information, to an XML message.
5. The TraCIM client submits the XML message containing the test results to the TraCIM server.
6. On receipt of the XML message containing the software evaluation report, the TraCIM client extracts the software evaluation report, decodes it and saves it in PDF format.

A corresponding standalone TraCIM client could take the form of a graphical user interface (GUI) that contains the following components:

- A “text box” in which the service user enters the order key.
- A “text box” in which the process key is entered.
- “Text boxes” in which the service user enters text to populate the software information elements.
- “Text boxes” in which the service user enters text to populate the tolerance elements.
- A “text box” that is populated by requests to be sent to, and responses received from, the TraCIM server.
- A “button” that when pushed implements steps 1 and 2 above, and displays the XML message received from the TraCIM server.

- A “button” that when pushed implements step 4 above, and displays the XML message to be submitted to the TraCIM server.
- A “button” that when pushed implements steps 5 and 6 above, and displays the XML message received from the TraCIM server.
- A “button” that when pushed closes the GUI.

Figure 5 shows the suggested layout of a standalone TraCIM client for a calculation that has two output parameters. Components coloured orange indicate “text boxes” while those coloured blue indicate buttons.

Figure 5: Layout of a standalone TraCIM client.

## Acknowledgments

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## References

- [1] TraCIM Computational Aims Database. <http://www.tracim-cadb.npl.co.uk>.