

Tribological Characterisation Services for Materials – i-TRIBOMAT

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Kurzfassung

Um den Entwicklungsprozess von neuen Komponenten zu beschleunigen, ist die Vorrausage der Eigenschaften der eingesetzten Werkstoffe im Betrieb der Komponenten von enormer Bedeutung. Um neue Werkstoffe hinsichtlich Ihrer Performance (in einer Komponente) bewerten zu können, ist deshalb die Entwicklung neuer innovativer Methoden notwendig. Diese Methoden können auch unter dem Begriff „lab-to-field“ oder „materials“ – up-scaling zusammengefasst werden. D. h. Werkstoffe werden im Labor charakterisiert, und deren Eigenschaften mittels z.B. Simulation auf die Komponentenperformance hochskaliert (up-scaling). i-TRIBOMAT ist ein EU gefördertes Projekt (H2020, GA Nr. 814494) mit dem Ziel ein Open Innovation Test Bed für tribologische Werkstoffcharakterisierung aufzubauen und entsprechende Services von der tribologischen Charakterisierung neuer Werkstoffe bis hin zu Simulationsmodellen zur Vorrausage der Performance von Komponenten der Industrie anzubieten. Durch die Bündelung von Knowhow und Infrastruktur zu Charakterisierung sowie den Aufbau einer digitalen Plattform, wird i-TRIBOMAT das weltgrößte Open Innovation Test Bed für tribologische Werkstoffcharakterisierung.

Schlüsselwörter

Lab-to-field up-scaling, Tribologie, intelligente tribologische Werkstoffcharakterisierung, Werkstoffdatenbank, geteilte Infrastruktur, Tribo-Analytik

Abstract

The prediction of the properties of the materials used in the operation of components is of enormous importance, in order to accelerate the development process of new components. To evaluate new materials in terms of their performance (in a component), the development of new innovative methods is necessary. These methods can also be summarized under the term *lab-to-field* or *materials* – up-scaling, meaning materials being characterised in a laboratory and their properties being upscaled to the component performance by means of e.g. simulation. i-TRIBOMAT is a EU funded project (H2020, GA Nr. 814494) aiming at building an Open Innovation Test Bed for tribological material characterization and offering corresponding services from tribological characterization of new materials to simulation models for predicting the performance of industrial components. By bundling the infrastructure, know-how for characterization and building a digital platform, i-TRIBOMAT becomes the world's largest open innovation test bed for tribological material characterization.

Keywords

lab-to-field upscaling, tribology, intelligent tribological material characterization, materials database, shared infrastructure, tribo-analytics

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Contents

This publication is a revised and up-dated version of the extended abstract presented during the 22nd International Colloquium Tribology. It includes all presentations of i-TRIBOMAT special session programmed in C9, D9, and E9 timeslots on Wednesday 29, 2020. The speaker and title are enlisted below:

- Franz Pirker (AC2T research GmbH, Austria): i-TRIBOMAT – The Digital Service Provider for Tribological Materials up-scaling
- Alberto Alberdi (Fundación TEKNIKER, Spain): i-TRIBOMAT Provides an Industry Driven Service Catalogue
- Álvaro García (Fundación TEKNIKER, Spain): Design of a Scalable and Interoperable Platform for Tribo-Connection
- Maria Kogia (ANSYS-Granta, United Kingdom): Materials Information Management for Tribology
- Helena Ronkainen (VTT Technical Research Centre of Finland, Finland): Collaboration Interface of i-TRIBOMAT
- Ichiro Minami (Luleå University of Technology, Sweden): Validation of Lab-to-Field Up-Scaling services
- Amaya Igartua (Fundación TEKNIKER, Spain): Building i-Tribomat Interconnections with Materials Ecosystem Interconnections
- Ivana Tóth (AC2T research GmbH, Austria): Panel discussion; i-TRIBOMAT – communicating an intelligent testing service of tribological materials

Nomenclature

- CAD: Computer-aided design
- CAE: Computer-aided engineering
- DoE: Design-of-Experiments
- EMCC: European Materials Characterization Council
- EMMC: European Materials Modelling Council
- FMI: Functional Mock-up Interface
- IoT: Internet of Things
- MMA: Moving mechanical assembly
- NOMAD: Non-destructive Evaluation (NDE) System for the Inspection of Operation-Induced Material Deg-radation in Nuclear Power Plants
- OITB: Open innovation test bed
- Parser: software construct that receives input data from a file

- PLM: Product lifecycle management
- REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals
- SEP: Single-Entry Point
- TM: Tribomodel
- TRIDAS: Tribologisches Datenarchivierungssystem
- TRL: Technology readiness level
- UI: User interface
- WR: Work room
- WT: Wind turbine

1 i-TRIBOMAT – The Digital Service Provider for Tribological Materials up-scaling

1.1 Introduction

The main idea supporting the project i-TRIBOMAT funded within the Horizon 2020 (GA Nr. 814494), is to develop the world’s largest user-driven open test bed enabling versatile tribological characterization of materials to support innovation in the European manufacturing industries, with an ultimate goal to reduce material up-scaling costs and time-to-market.

In the field of tribology, renowned institutions combine their testing and analytical as well as simulation capabilities in a Single-Entry Point (SEP) in Europe.

The aim of i-TRIBOMAT is to build up the necessary infrastructure to provide tribological materials characterisation services. This means a:

- 1) shared tribological infrastructure with more than 100 tribometers and characterization equipment together with new protocols, tribo-analytics, design of experiments and online data acquisition system.
- 2) secure IT-platform for data mining, connecting, harmonising, managing, analysing and sharing capability.
- 3) collaboration interface for interacting with customers from industry, educational and research institutions.

These three modules will be accessed by external customers via the Single-Entry Point (SEP).

By linking existing characterization infrastructure and developing new (digital) services, industry will be provided with a cost-effective means of material characterization and up-scaling (i.e., prediction of system properties) of new or alternative materials. The SEP is the sustainable new legal entity that will operate the i-TRIB-

MAT Open Innovation Test Bed and will be established by the founders AC2T, TEK, VTT, AN-SYS-GRANTA and BAM.

As the future legal entity, the SEP will act as a unified publicly accessible spot. This approach represents a typical digital business model.

1.2 The interacting units of i-TRIBOMAT

The main concept of i-TRIBOMAT, shown in **Figure 1.1** consists of four interconnected units. The connection of these units represents the Open Innovation Test Bed.

1.2.1 Shared Infrastructure

All the tribological characterisation equipment of the five European Tribology Institutes AC2T research GmbH (AT), BAM Bundesanstalt für Materialforschung und -prüfung (DE), VTT Technical Research Centre of Finland Ltd (FI), Fundación TEKNIKER (ES), Luleå University of Technology (SE) are connected via Internet of Things (IoT) technology with the IT-platform. Combined with newly developed and standardised protocols and procedures of the test benches, the shared infrastructure ensures direct comparability of acquired tribological tests. With the large number of tribometers and characterisation equipment of these partners, the largest intelligent tribological test centre is being built.

1.2.2 IT-Platform

The IT-platform enables data management, data sharing and data analytics, considering all security and safety issues. Additionally, a tribological material database will be set up. Since the Single-Entry Point (SEP) works as a one-stop shop, not only characterisation services are offered to customers, the SEP also supports the customers with **data-driven services**, such as data storage, data sharing and data analytics.

1.2.3 Collaboration Interface

The Collaboration Interface plays a central role in the integration of different software tools and offers an interactive access to the shared data for various end-user groups. Its architecture enables cost-effective integration of material models and dynamic solvers to predict the system-dependent tribological behaviour of materials, like the lifetime or energy efficiency of various machine components. Within this unit the materials up-scaling with lab-to-field simulation models will be performed.

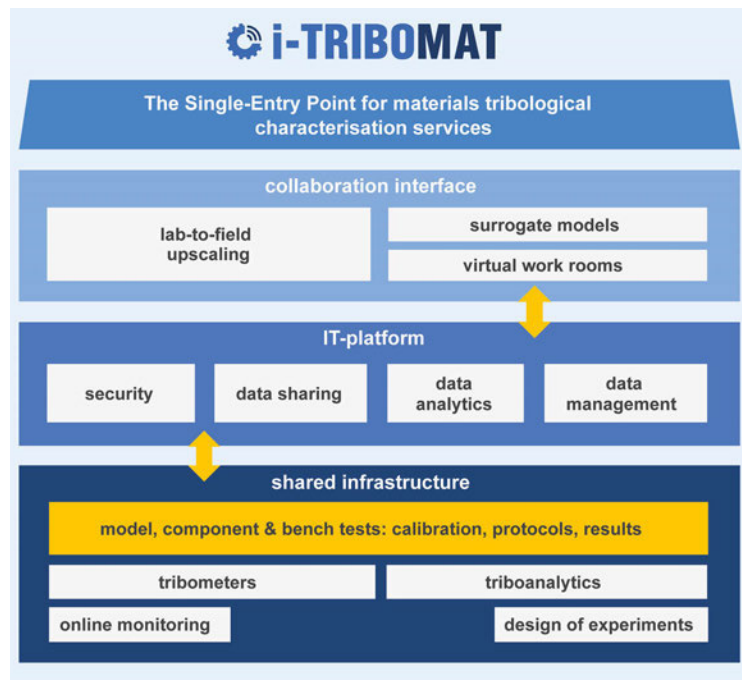


Figure 1.1: Main concept of i-TRIBOMAT

1.2.4 SEP Single-Entry Point

The SEP as the new legal entity will offer all new tribological characterisation services to customers and will be founded by the partners mentioned above.

1.3 Workflow of a typical customer request

For the up-scaling of materials the overall workflow including the different services is shown in **Figure 1.2**.

The industrial requirements formulated by the customers, such as (new) materials or product design, including the operational conditions are the basis for the down-scaling process. This down-scaling represents the so-called field-to-lab approach to select the tribological testing procedure closest to the real application. Prior to any tribological testing of materials, a proper Design-of-Experiments (DoE) optimises the test matrix to increase the time efficiency and reduce the testing costs.

The resulting tribological material characterisation data will be stored on the IT-platform in a harmonised way. These harmonised and comparable data as well as data-driven services such as data analytics, data storage or the usage of AI-methods will enable a multiple reuse of previously generated data – via experiments or simulation. Additionally, these harmonised data will form the basis for the so-called lab-to-field materials up-scaling approach. This service will be implemented in the collaboration interface. Virtual work rooms facilitate collaboration and surrogate models can be used as replacement of high-fidelity models when rapid answers are required. Via surrogate models and numerical simulations in virtual work rooms (see **Figure 1.1**).

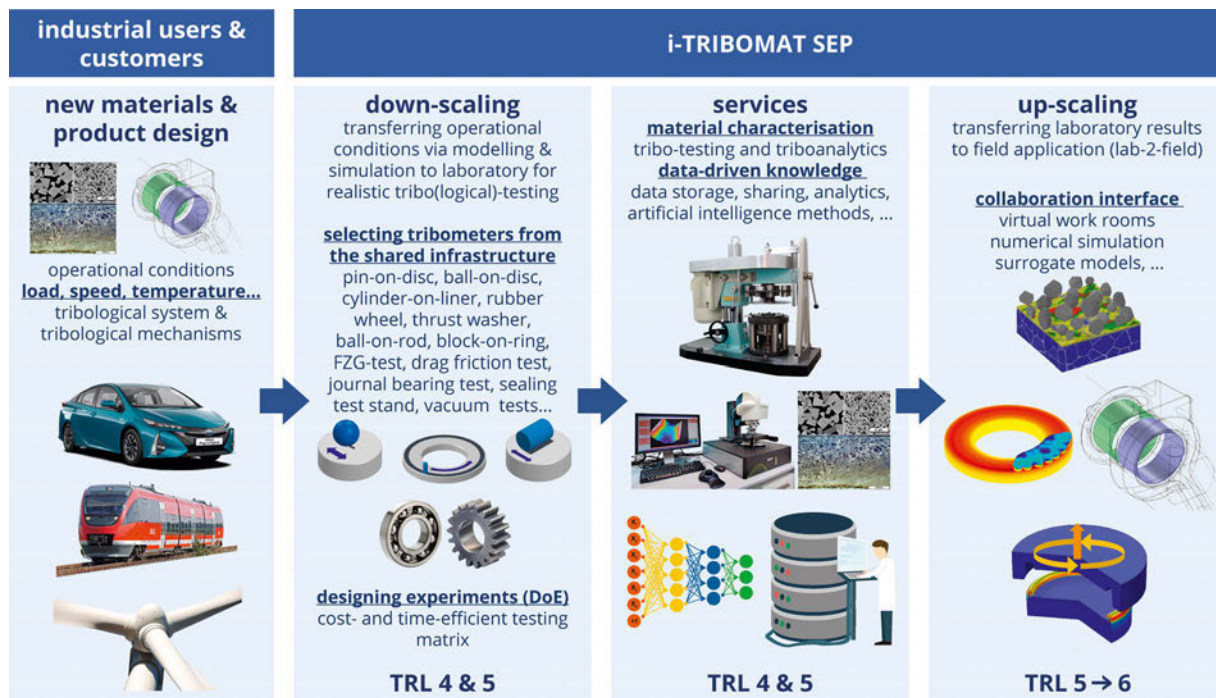


Figure 1.2: Workflow of i-TRIBOMAT

Finally, the SEP is the one-stop shop and entry point for the customer and enables the filing of requests as well as the easy selection of appropriate services for each specific customer need.

1.4 Creating new (digital) business models

The main motivation of i-TRIBOMAT is to share knowledge, infrastructure and multiple use of experimental as well as simulated results to become the best provider of

tribological material characterisation services in the world. The approach to share infrastructure, building up new services and selling them through a Digital Platform represents a typical Digital Business Model like Airbnb or UBER. The value chain from the infrastructure suppliers through the service provider and the customer is shown in Figure 1.3.

The founders (enlisted in chapter 1.1) are setting up the SEP, as the future channel for commercialisation that

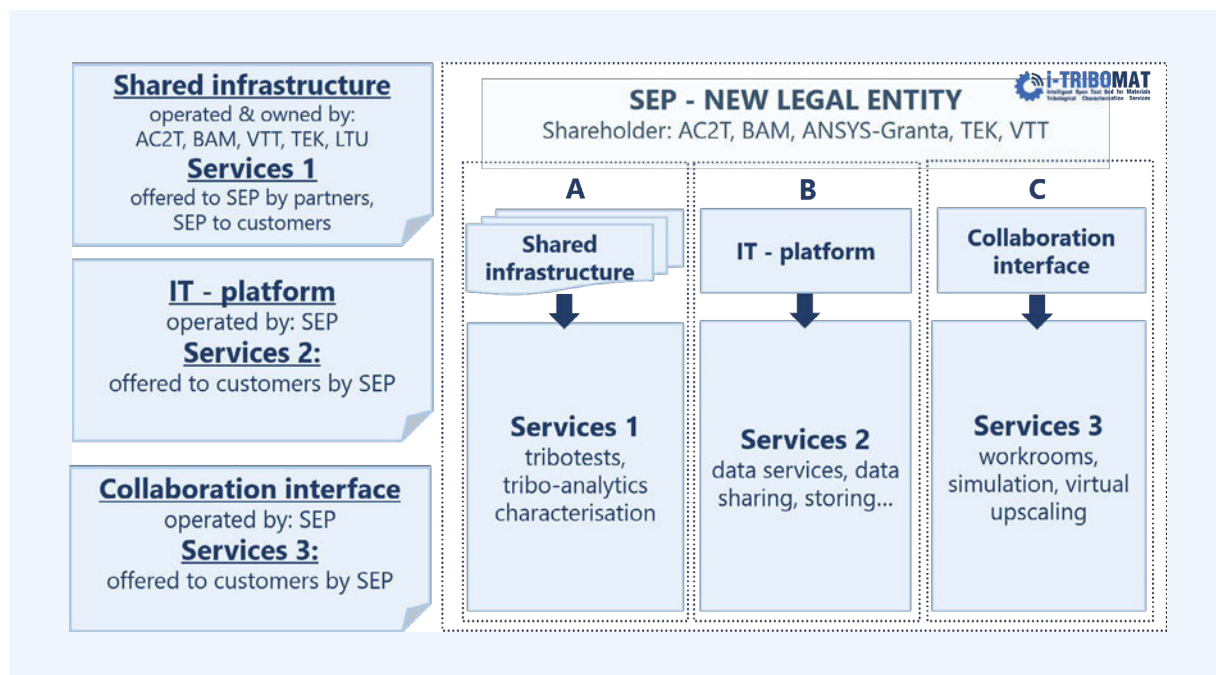


Figure 1.3: Value chain and digital business model

exploits the tribological material characterisation services of i-TRIBOMAT directly to the market. This joint venture (SEP) will enable the creation of new digital services and requires new digital business models between all stakeholders.

2 i-TRIBOMAT Provides an Industry Driven Service Catalogue

2.1 Scope

This chapter presents a summary of the main services that the Open Innovation Test Bed i-TRIBOMAT provides to the European Industry for the tribological characterization of materials, which include three service categories (see **Figure 1.3**):

- Services 1: Tribological and surface characterization tests
- Services 2: Data driven services such as data sharing, data storing or data searching services
- Services 3: Simulation based services for up-scaling.

This service catalogue includes a holistic virility of services and additionally defined case studies for a wide variety of applications. Some examples refer to different tribological characterization tools for material selection and benchmarking of new materials against conventional solutions. Other services deal with running-in and long-term wear as well as friction performance of a wide range of materials, for example, steels, cast iron, light alloys, ceramics, polymers, composites, seals, coatings and newly developed categories. Joint capabilities allow the tribological characterization of materials in different environments, such as vacuum, very low or high temperature and corrosive atmospheres. A large range of new testing equipment and protocols have been developed to simulate experimentally the failure mechanisms and working environments [1].

Lifetime prediction of components is another sort of service provided by i-TRIBOMAT. Such lifetime prediction is based on data gained in experimental laboratory tribotests and includes computer simulations supported by database searches and artificial intelligence algorithms.

Finally, the i-TRIBOMAT catalogue also includes lubricant analysis and lubricant performance characterization tests. i-TRIBOMAT provides the European Industry with all these characterisation tools, which will allow a better knowledge of the behaviour of materials under high friction and wear conditions and a better prediction of the lifetime of components. In future, this will lead to a better, faster and much cheaper choice of materials in the design process of components. In this way, tribology will help to implement materials solutions into energy and resource efficient, sustainable systems as well as

products and processes, thus contributing to the reduction of carbon footprint.

2.2 New approach for the tribological characterization of materials

The tribological characterisation of materials at laboratory level (TRL 3-4) is usually carried out with universal tribometers with rotating unidirectional or reciprocating movement, which can simulate different mechanical contact situations under numerous environmental conditions, i.e. temperature, humidity, vacuum, lubricants or possible corrosive atmospheres. These tribometers normally use model samples of small size and simple shape, such as discs, pins, balls or cylinders, made of the new material under characterisation. Therefore, tribological characterisation of materials at laboratory level is fast and cost-effective. However, to upscale tribological characterisation of materials at component or mechanical system level (TRL 5-6) like valves, cylinder lines, gears, roller or ball-bearings, seals, etc. complex and very expensive test rigs are needed, particularly developed for each specific application. Several partners in the project have large experience in designing, building and setting up this kind of test rigs. Regarding the samples, it is necessary to manufacture the components to be tested, which must be made of the new material intended to be scaled up. Finally, these tests are typically performed until the end of the service lifetime of the component, which means that the test rig can be occupied for weeks or even months for a single test. Therefore, these tests are more time consuming and costly, but are very valuable for validation purposes. This causes up-scaling to be one of the most important barriers to the incorporation of new advanced materials in some industrial sectors such as transport, wind energy, machine-tools or mechanical capital goods. **Figure 2.1** shows an example of a test bench, specially designed by TEKNIKER for the tribological characterization of seals that will be available for the OITB of i-TRIBOMAT [2].

The i-TRIBOMAT characterisation services will be made accessible via a specifically designed IT-platform



Figure 2.1: Test Bench for Tribological Characterization of Seals © TEKNIKER

and a linked web-based customer interface, which allows for data management, analytics and mining, new modelling tools and even virtual trials in real operational environments. This will contribute to reduce significantly the costs and time by limiting the use of large-scale component tests to validation purposes.

2.3 Service Catalogue Structure

The methodology followed to build the service catalogue was to define each of the functions the Test Bed will perform as independent modules for the provision of the services. These service modules are standalone, complete in itself. The tasks to be carried out in each service module are properly described, standardised and predefined. In each of these modules, input and output data of a preestablished nature are defined, as well as the different roles played by the operators and experts in charge of carrying out these functions in the respective modules.

Figure 2.2 shows an example of a service package consisting of different modules, such as experimental tribo-tests, surface analysis of samples and Lab-to-Field model up-scaling.

According to the customer's requirements, each service has been designed adhoc, linking different modules from the catalogue. Therefore, the i-TRIBOMAT service catalogue will be a catalogue of modules through which a potential customer will be guided to compile the optimum services for his/her requirements.

This catalogue of modules includes technical functions (tribological tests, characterization of samples and their surfaces, database searches, data analysis, numerical simulations) and administrative functions related to the management of the service (arrival, distribution of customer requests/samples, provision of quotations, reporting, invoicing, status reports).

2.4 Prospects

In the coming years The Open Innovation Test Bed i-TRIBOMAT will supply the European Industry with new services for the tribological characterization of materials. These new services combine conventional laboratory scale tribotests with data driven tools, like federated data analytics, database searches or simulation tools

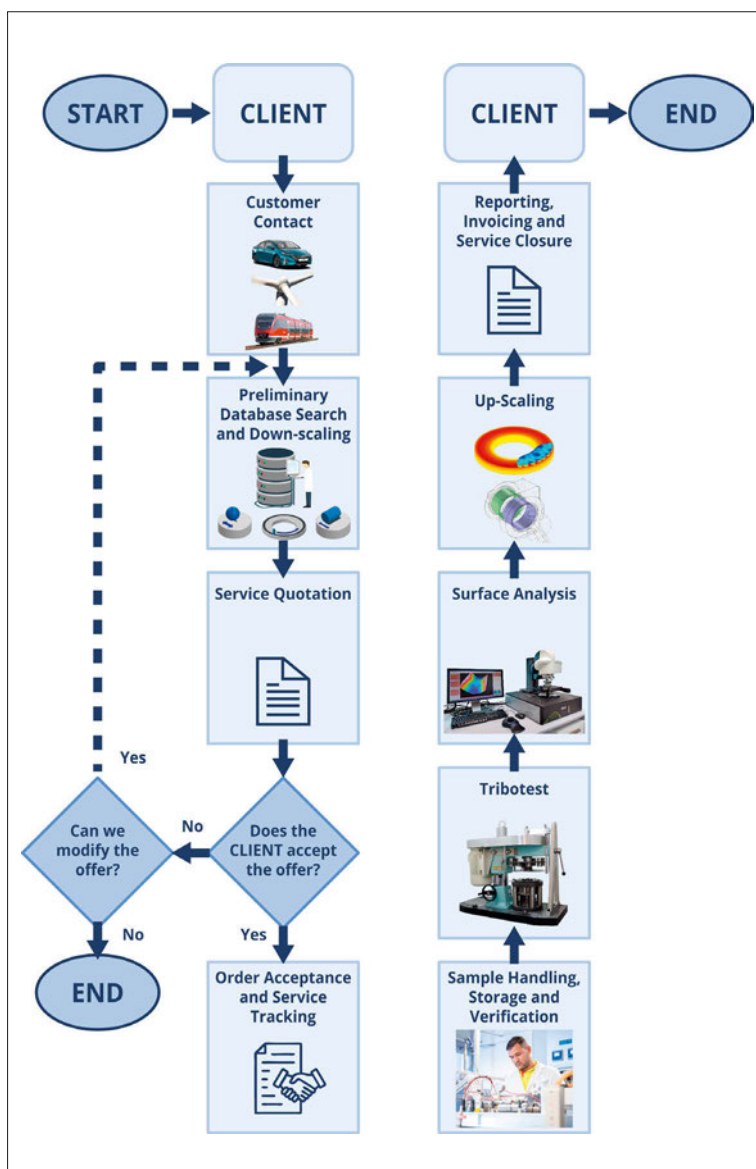


Figure 2.2: Example of Service Package Workflow

like e.g. finite element modelling. They all together enable the up-scaling of laboratory scale tribotest results to friction and wear behaviour of real components or whole systems. An innovative approach of this catalogue is its service module structure.

This allows to adjust each service optimally in complexity and cost to the specific need of each customer. In addition, the service module structure allows the implementation of standardised workflows. These workflows allow the efficient and reliable handling and processing of customer requests and orders.

3 Design of a Scalable and Interoperable Platform for Tribo-Connection

3.1 Scope

To offer all proposed services (see 2.1) during the i-TRIBOMAT project, one of the objectives includes creating

an infrastructure in order to link existing lab equipment from different partners with the data platform. TEKNIKER has experience in developing Triboconnectors to cover this functionality. This section will explain the architecture of the different elements involved in the proposed solution: the shared equipment, middleware and data platform; and how they will be used to provide a more connected tribology approach.

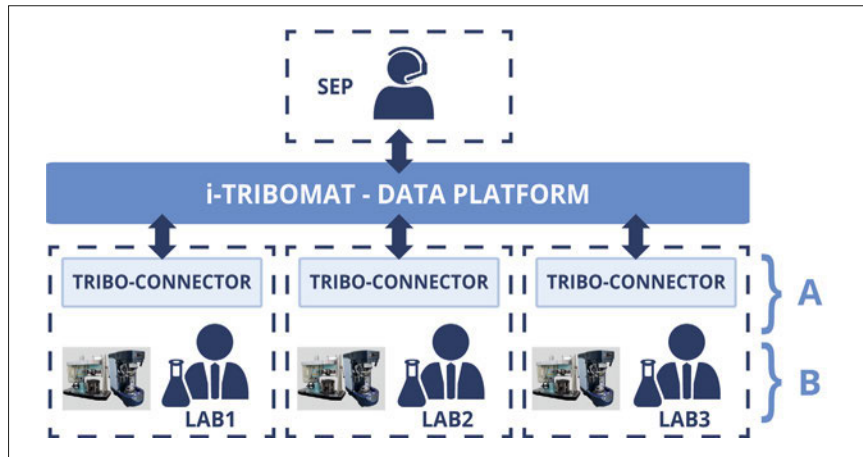


Figure 3.1: General architecture, A: Middleware, B: Shared Infrastructure

3.2 General architecture

The architecture will follow a three-layered approach. Equipment, middleware, and platform (see Figure 3.1).

The lowest layer represents the physical domain, mainly the equipment and devices involved in tribological tests. In i-TRIBOMAT’s case the equipment will be used in a collaborative manner and will be referred to as the shared infrastructure.

The middleware layer will act as connector between the physical devices (equipment) and the internet (data platform), providing a series of functionalities. It will not be a single element, but rather a group of various tribo-connectors, one for each tribological laboratory. Additional tribo-connectors can be added following this approach, making it possible to add tribological laboratories in a scalable manner.

The data platform will act as a core repository and functionality vault, storing the data gathered from other layers and hosting services that will exploit the data. In i-TRIBOMAT’s case, the services will be exploited by the Single-Entry Point (SEP).

This type of architecture is common in use cases involving different data sources and requiring certain degree of centralization. TEKNIKER has used similar architecture in previous EU projects such as Zonesec [3], Local4Global [4] and Respond [5].

3.3 Shared equipment

The shared equipment refers to the pool of the resources from different partners as one. While the equipment is still managed and operated by the individual partners, a wider selection of services is made available for the clients. Additional mechanisms need to be defined in order to balance the workload in a “fair” manner: while one service may require the use of a specific equipment owned by one partner, and another service can be offered using equipment owned by multiple partners.

3.4 Middleware

The middleware layer will act as a mediator between the shared infrastructure and the data platform. It will provide a series of functionalities:

Tribological test, equipment information and work order

Management:

- Remote connectors to data platform
- Tribological files and data uploading services
- Graphical user interface
- Local data persistency (optional)

And when available:

- Data acquisition protocols
- Commercial equipment files parsers (software construct that receives input data from a file)
- Security and safety tools

The middleware will have a modular approach. While the functionalities remain the same, some components may have different implementations or may not be needed: the protocols and parsers will vary between different laboratories, as each one will have different equipment.

3.5 Data platform

The data platform will provide a series of functionalities primarily focused on data management, covering secure data storage, access and exchange. Main goal is to define and implement a central materials database for materials tribological characterisation, responsible to manage existing material data such as properties, sample history, etc.; and the data generated before and after tests for tribological materials characterisation and analysis (tribo-

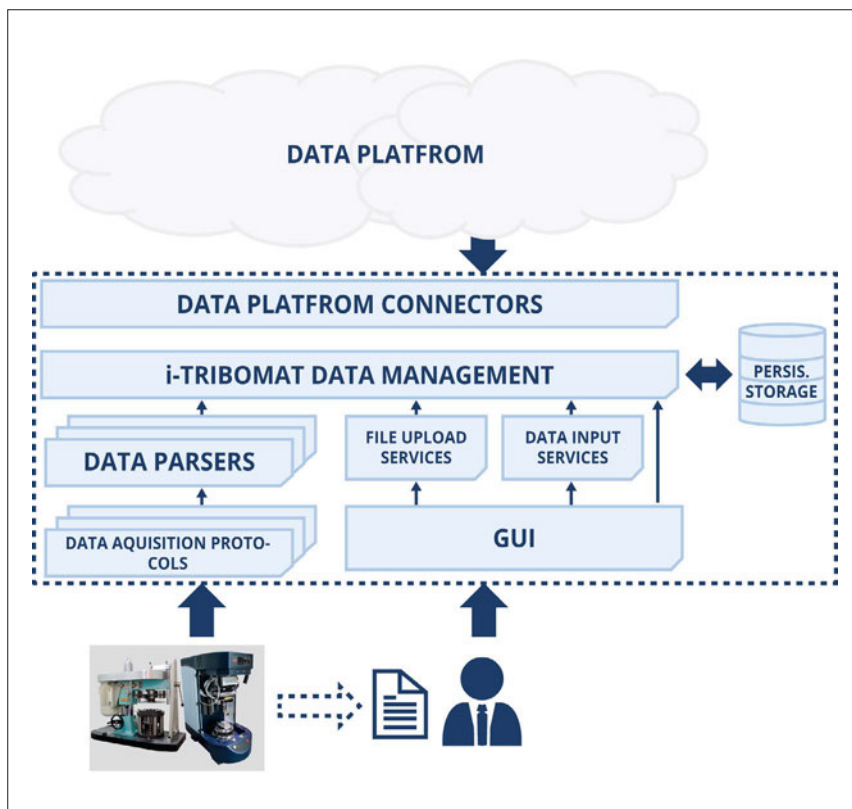


Figure 3.2: Middleware structure

analytics). Therefore, covering not only materials but also capabilities for managing, sharing and analysing tribological test data.

Hence, it will be responsible for providing mechanisms to harmonize / standardize acquired data by establishing common protocols for parametric data storage. It will also provide open interfaces that facilitate interoperability and integration of data from other sources, allowing the creation of interlinked material, with tribological, ecological and other databases such as REACH, CAS, NOMAD and TRIDAS, initiatives such as EMCC and EMMC or other OITBs.

matic manner, making possible to set parameters, make measurements or trigger alerts based on different conditions during the lifetime of the experiment. The output of the experiments can be automated to be stored in different manners. The experiments can be queued based on the availability of the machines or manually managed through a user interface, which also provides information of the status of the experiment and realtime monitoring of their values.

Initially aimed for internal use inside AC2T laboratories, the software has been designed in a highly configurable approach, making it possible to interact with common data acquisition equipment such as National Instruments cards. Its modular approach eases the inclusion of new functionalities such as the connection to the future i-TRIBOMAT data platform, or the visualization of historic data of previous experiments.

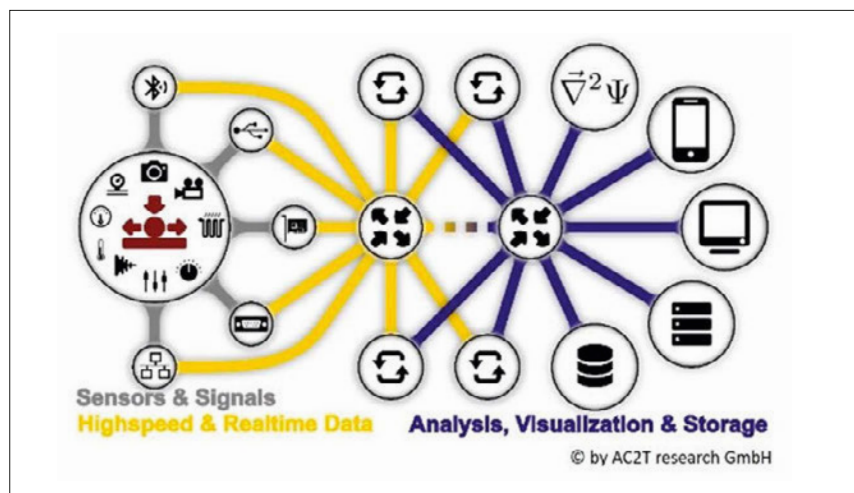


Figure 3.3: Equipment control and data visualization

In addition, Open Interfaces will be offered in order to interact with the Data Platform at different levels, allowing communication with the middle-ware as well as with external entities. This will translate into i-TRIBOMAT service requests and the corresponding orchestration of actions, providing services like tribological analysis commissions, simulations and material information data searches based on semantic technologies.

3.6 Control of equipment: AC2T-Tribosoft

In order to manage and automate the tribological tests as well as the equipment involved, AC2T is developing a software called Tribosoft. It allows to define tribological experiments, configuring the equipment in different steps of the experiment in a program-

3.7 Towards connected tribology

The middleware was designed in order to provide certain functionalities usually seen in the IoT (Internet of Things) approach:

- **Secure connectivity.** Web based communications based on standard communication protocols.
- **Dynamic and heterogeneous.** The modular approach makes it possible to add new equipment interfaces without changing the middleware core. The framework is adaptable and configurable to different implementations, following the plug and play approach.
- **Distributed and scalable.** New laboratories can be added and integrated to work together.
- **Data ownership.** Experimental data is shared in a secure manner. The ownership will be set by the different future business relations via the SEP.
- **Intelligence.** Combining the collected data from different laboratories with open material databases could provide better analytics, more complex simulations and up-scaling of components.

3.8 Prospects

The platform design presented offers a novel approach, as it intends to apply already consolidated methodologies and technologies to the tribology field. It aims to offer a tool to encourage collaboration between different laboratories by providing common data models, automation tools and communication capabilities, aligned with current EC standardization projects.

4 Materials Information Management for Tribology

4.1 Scope

Materials information is typically stored on paper, in assorted spreadsheets, or in generic database systems not designed for materials information. Expert tools that analyse or use materials data, tend to be isolated requiring manual input/output of data resulting in scattered data sources within a department or organization. It has been concluded that such an approach can cost an organization millions of euros in lost productivity, repeated tests, lower product quality, higher risk, and missed opportunities for innovation.

Across the field of tribology, the difficulty of overcoming materials information management problems is amplified by the fact that: tribological applications exist in every industrial sector, and as such require agreement on an intensive pedigree to describe complex environments, equipment set-ups, and multimaterial systems; lack of internationally accepted characterisation standards which leads to subjectivity in results; and a large number of specially designed tribometers and testing jigs meeting the requirements of niche applications.

In the i-TRIBOMAT project, a customised materials information management system for tribological applications is being developed to address the above challenges based on the commercial software GRANTA MI to enable the capture and sharing of information for harmonization across the supply chain. Materials related information generated throughout the entire value chain of tribological studies, including physical test and simulation data, statistical and design data as well as agreed metadata, are stored in a centralised data management system that ensures data traceability and searchability and facilitates model validation. It has been described how the complexity of tribological datasets effect the design of a centralised database for the harmonization of tribological datasets across a distributed network of partners.

4.2 Challenges

As already stated by Feynman as early as 1963, aside from the material, the interfacial and ambient conditions are of equal importance to quantify friction and wear, which are not properties of a single material, but system properties. According to Czichos [6], they refer to the entire tribological system that consists of:

- the sample and counter-body in contact (see **Figure 4.1**),
- if applicable, separated by an intermediate body,
- forced to move relative to each other under a certain load (e.g. in a testrig),
- surrounded by a (technical) environment.

Therefore, a materials data management system for tribology should capture information generated from the value chain of entire tribological systems. This includes complex materials pedigree (metals, ceramics, and thermoplastics), test setup and conditions (e.g. ambient pressure, temperature, medium, etc.) and equipment used.

Currently, there is a large number of specially designed tribometers and testing jigs available specifically ad-

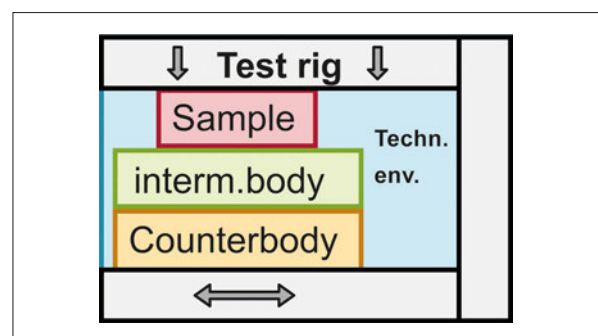


Figure 4.1: Sketch of the components of a tribological system

addressing the requirements of niche applications. Each tribometer is optimised to simulate a specific tribological contact situation. The lack of internationally accepted characterisation standards can lead to low comparability as resulting data will mostly be incoherent. The respective wear scars created in the tribological tests are currently characterised by a variety of tools which can result in even more diverse datasets of images, profiles, spectra or chemical distribution maps. A centralized materials information management system is a key objective of this project in order to enable standardised capture, consolidation and harmonization of tribological information, metadata and knowledge. Tribological materials data generated in experiments and modelling/simulation in the project along with agreed metadata are stored in the database and provide full traceability of tribological materials test.

4.3 Architecture for Tribological Database

Underpinning GRANTA MI is a schema capable of structuring the pedigree of information of a tribology system from material batch, process parameters, technical environment, to detailed physical and virtual characterization tests and analysis. The schema enables searchability, mapping of data and meta data attributes, and traceability of information (links and relationships). Full traceability is a challenging information management issue, since the network of connections between data points builds-up rapidly as test data are produced, analysed, fused, and reported in various formats. This level of information management was designed for rigorous qualification and certification reporting, whether in-house or to regulatory bodies, and has been validated by industry and researchers for over 20 years. GRANTA

MI is the leading system for materials information management in engineering enterprises.

Figure 4.2 outlines the main component and functionality of GRANTA MI. The system is installed on a server for enterprise network or web access; distributed access to a central source of materials information is enabled for customers with appropriate access control and security measures. The database is explicitly designed to manage specialist materials and process information and can host in-house data, external reference information, or a combination thereof. Many types of data can be stored, and their import/export automated for searching, advanced analytics (bespoke or commercial tools such as MatLab®), visualization, automated workflows, assignment to specifications and parts in CAD/CAE/PLM commercial software, and reporting against regulations such as REACH. Workflow automates the transfer of data/information for tasks such as authoring, signoff, test scheduling and digitisation of characterisation protocols, as needed for material selection/substitution and Round Robin tasks to meet tribology specifications.

Here, we explore the complexity of tribological datasets and its effect on the design of a centralised data-base for the harmonization of tribological datasets across a distributed network of partners.

4.4 Prospects

i-TRIBOMAT is an EU funded, research project that focuses on tribology and amongst others it aims to develop a centralised data management system for tribological materials information for this field by 2022. Due to the complexity of a tribological contact and the multi-mate-

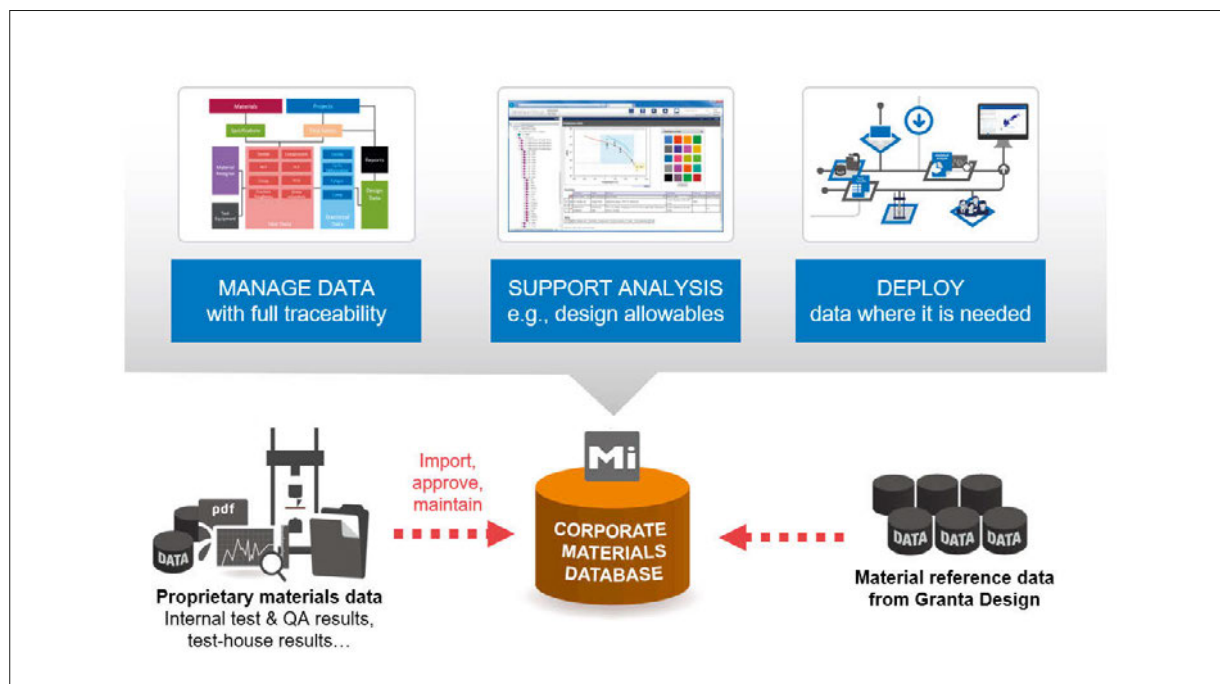


Figure 4.2: Test data management solution based on GRANTA MI

rial nature of samples, full traceability can be a challenging information management issue that can be tackled with appropriate customisation of GRANTA MI. This and other challenges faced by designing a tribological database are considered in the present contribution.

5 Collaboration Interface of i-TRIBOMAT

5.1 Scope

As defined in Section 1.2.3 the Collaboration Interface is the web-based entry point for customers to the up-scaling services. These services can be accomplished via different virtual workrooms (WR). Within this unit the materials up-scaling with lab-to-field simulation models or surrogate models based on tribological test data will be performed.

5.2 Collaboration Interface – Content & structure

The essential content of the Collaboration Interface has been depicted in **Figure 5.1**. The interface hosts two types of catalogues: The work room catalogue shows all the different projects, which are accessible to users. Users can open a new work room when beginning e.g. to study a new tribological problem, or they can join an on-going project according to their interests. The Tribo Model (TM) Catalogue comprises all the simulation models published by the users of the Collaboration Interface. Interested parties can survey the models and see, if any of them could be useful in helping to solve their specific modelling problem.

Typically, tribology related design and modelling task require a combination of simulation models and meas-

urement data obtained from and operating on different scales. Therefore, the Collaboration Interface must enable the co-use of different models. The technical functionality of the Collaboration Interface supporting the building of multi-scale tribo-simulation models (i.e. composite models) is referred to as Lab-to-Field up-scaling.

5.3 Lab-to-Field up-scaling functionality

On the right-hand side panel of **Figure 5.1**, we have illustrated the contents of a generic work room (WR). In the work room the user can find a list of models (from the Tribo Model Catalogue), whose *combination* will help answering some practical questions requiring the use of models operating on different fields or scales. In this specific example, model TM2 could represent, for instance, a multibody simulation model of machine parts and model TM5 could provide the simulated lubrication related parameters as well as data. The composite model denoted as *TM2+TM5* can then provide insight into the behaviour of lubricated machine parts.

Generally speaking, the underlying motivation for supporting model and simulation-based up-scaling features is to decrease the number of expensive component and higher scale experiments by replacing and supplementing them with experimental studies with small scale tests combined with numerical design. The simulation models to be distributed and used through the work rooms are not meant to replace the high-performance computing clusters running extremely detailed tribo-models by research institutes and universities. Rather, it is supposed to complement these by offering a possibility to upload into the model catalogue faster substitutes for the detailed models, so-called surrogate models, which are more suitable for searching ideal parameter values in multi-optimization design problems. The Lab-to-Field up-scaling functionality supports surrogate model co-use based on the Functional Mock-up Interface standard. This standard can also be used to integrate other types of models than surrogate models with each other.

5.4 Prospects

Model-assisted collaboration: The user setting up a work room on the Collaboration Interface can invite a group of collaborators (other modelers) to share simulation source codes with and to build a common user interface (UI) for the composite model. An example has been provided in **Figure 5.2** below.

The software tools of the Collaboration Interface enable the publication

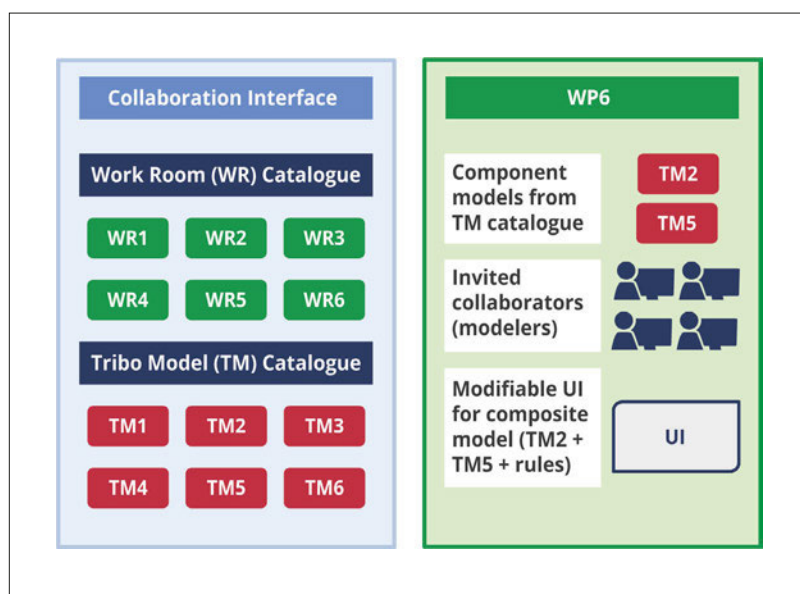


Figure 5.1: Conceptual view of the Collaboration Interface and a work room. UI refers to User Interface.

of the UI as an interactive web application, through which users can perform operations to visualize the numerical outputs of the simulation models, perform design optimization etc. Unlike the construction of the models, using the UI does not require special technical skills or necessitate software installations.

6 Validation of Lab-to-field up-scaling services

The validation step will *prove the platform through evaluation of materials for selected use cases*. Feed-back from the test bench results (TRL6 and higher) performed by the industrial partners will improve the database as well as the simulation tools continuously.

6.1 Scope

Most laboratory tribotests have been developed for simulating material failure in a particular system. Examples are laboratory tests on wear rate, load-carrying capacity, surface fatigue, or friction and wear phenomena. These tests usually involve simplified laboratory equipment to extract a particular aspect. The tests are often performed under accelerated conditions with respect to temperature, load, and/or velocity, for example. The results are beneficial for improving the tribo-system by tuning operating parameters, contact design, materials, and/or lubricant components. Contrary to mechanical tests and failure analysis, laboratory tribo-tests are not yet fully applied in material design and development. *There is a tacit consensus among tribologists about mismatching between laboratory results and practical performances*. Under these circumstances, laboratory tribotests are rather insufficient to screen candidates at early stage of material development. The screened materials prior to be commercialized are then subjected to several phases of evaluation through time and cost incentive manners. This work package acquires evidences for “lab-to-field up-scaling” in material development, which brings “a shortcut from laboratory to the real world.” As addressed previously, “materials characterization services catalogue” defines i-TRIBOMAT services that are composed of “Shared infrastructure,” “IT-platform & databases,” and “Collaboration Interface.”

6.2 Validation procedure

According to the specifications from existing systems, the requirements for materials will be determined and consequently proper laboratory test set-ups will be selected, considering operating parameters (geometry of contact, contact stress, relative velocity, and mode of motion), environmental parameters (temperature, rela-

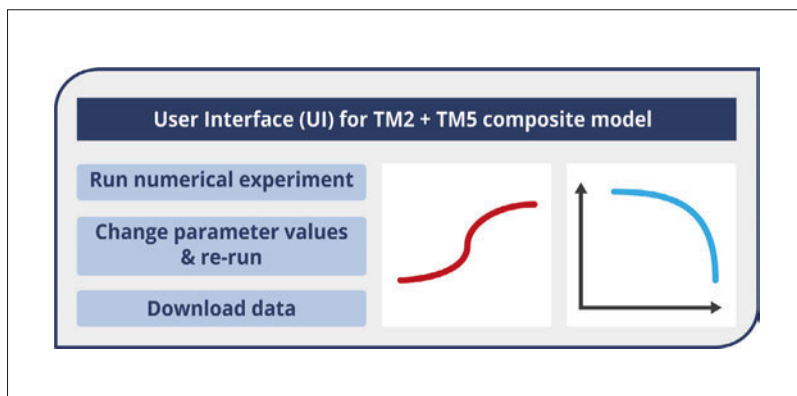


Figure 5.2: Conceptual view of a user interface

tive humidity, lubricant components, possible contaminants), and machine performances (power generation capacity, energy efficiency, and lifetime of machine component). All these features will define the lab-scale model test(s) to be performed. The up-scaling procedure will be validated by carefully comparing field performance data of real sized-component tests (performed by the industrial partners) to the results generated by i-TRIBOMAT up-scaling tools. Subsequently, the materials up-scaling will be assessed which shows the quality of predicting material behaviour, e.g. wear-rate. Three different commercial full scale tribo-systems were chosen for validation (see Figure 6.1);

(1) Tribomaterials of gears and plain bearings for green energy generation, particularly wind turbines (WTs). A gearbox in WT systems increases the speed transmitted from the rotors to the generator that leads efficient power generation. As the demand of more power generation, the generating capacity and physical size of WTs are growing. It requires improved gearboxes to generate higher revolutions. As results, materials in gearbox experience higher contact stress at low velocity (from rotor) and higher thermal stress at high velocity (to generator) in sliding-rolling motions. Robustness and reliability of the materials under harsh conditions are of importance because maintenance is costly. As alternatives to currently using steels, such as coatings are emerging with high wear resistance and low friction. A focus is put on the prediction of the efficiency and long-term durability in continuous operation. The main challenge is up-scaling of material characterization to full-scale WT systems composed of large gears and bearings. Based on the specification sets from the field applications, the requirements for gear and bearing materials will be determined and then the needs for up-scaled materials will be identified. Special care has to be set on the transfer of practical loading conditions from the available field data including environment parameters and clarifying the operating parameters that load on the material.

(2) *Powertrain systems in vehicles* are composed of a large number of moving mechanical assemblies

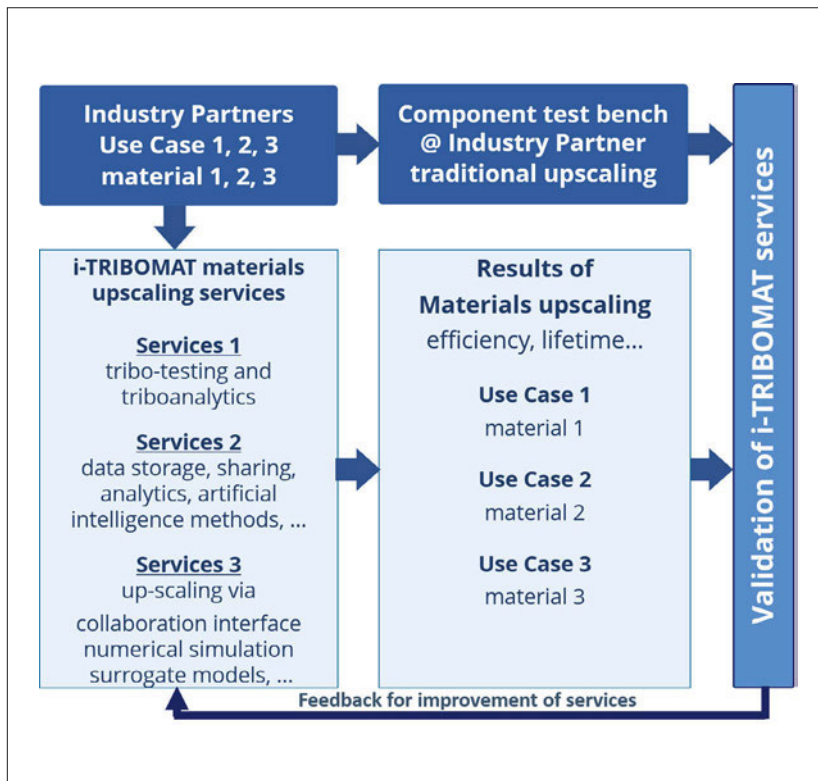


Figure 6.1: Validation procedure of i-TRIBOMAT services

(MMAs) and materials. The total efficiency of the component is determined by each MMA, which is designed to operate under mediumload and high-velocity conditions. Currently, cast iron, aluminium, and coatings on them are the most used materials. Lightweight materials are emerging. The Lab-to-Field up-scaling tool will be applied to new materials for the prediction of energy efficiency conditions. The main challenge is to predict the energy efficiency (friction regime and level, respectively) of materials and different surfaces. Based on the specifications set by the applications, the configuration of each MMA and the combination of MMAs in the system will be clarified. The governing operating and environmental parameters for each MMA will be determined. A selection of MMAs will be done with respect to friction. Then, the necessary amount of tribological measurements will be defined and generated in order to adequately perform AI, supplemented by numerical modelling and simulation. Thereby, the tribological performance of new and used samples from engine parts – covering two engine specifications – will be evaluated with model tests. Online sensors will acquire outputs (friction force, wear depth, vibration, and acoustic emission) during the tests. The experimental data will be processed and compiled for each MMA. Multi-scale tribological simulations will be performed to elaborate the dominating friction laws. The simulation results will be compared to the expected performance in engines to verify, if these friction laws are indeed dominant. Based on the friction laws established, AI methodologies will be considered for benchmark correlations and eventually validated via engine tests.

(3) *Seals in hydraulic systems* have to prevent leakage of fluids in operation. A compromise is required between good sealing and tribological performance. The common seal materials are elastomers and thermoplastics that slide against steel. Due to lack of testing standards, there is a huge demand for seal materials development. This use case focuses on lip seals for hydraulic systems. The tribological performance of novel self-lubricating materials will be utilized and further developed for seal-contacts by making use of the tools provided by the i-TRIBOMAT consortium. The challenge is to develop standards for seal testing supported by online sensors and numerical simulations. Based on the specification sets by the applications, the main operating and environmental parameters in the real application will be compiled. For the seal material up-scaling, the output parameters from tribological performance tests are defined, such as friction, maximum leakage and system efficiency (friction). A component test rig for seals attached with proper online sensors will be employed for the validation. Novel self-lubricating materials based on thermoplastic polyurethanes, hydrogenated nitrile butadiene rubber and fluorinated-elastomer materials, will be evaluated. Friction, wear and oil leakages will be monitored in real time. The functionality and accuracy of online sensors will be evaluated towards test standardization. The prediction tool for efficiency of seals will be validated by comparing the performances at various “sealing pressure versus shaft velocities” and temperatures.

6.4 Prospects

For validation of services applied in use cases, one identifies the similarity and dissimilarity of laboratory test and component test for each use case. Then, one clarifies and prioritizes the significances of laboratory and component tests as measurable criteria. The results will be recorded onto i-TRIBOMAT database. In order to make accurate up-scaling, down-scaling will be reconsidered for the validated results of models to identify optional and additional testing parameters or monitoring. The validation procedure, developed and dedicated to the validation of Lab-to-Field up-scaling tools, will be assessed and integrated as part of “continual improvement process.” i-TRIBOMAT is not limited to three use cases above. *i-TRIBOMAT platform will be extended to materials for various tribological systems* after full validation via these three use cases.

7 Building i-TRIBOMAT interconnections with Materials Ecosystem

7.1 Scope

i-TRIBOMAT is building the world's first **Open Innovation Test Bed (OITB)** dedicated to validating and up-scaling new materials enabling intelligent Tribological Materials Characterisation and fostering industrial innovation in the European manufacturing industry. Tribology is an excellent tool to define the suitability of advanced materials to be applied for the design of energy efficient products and processes [7]. i-TRIBOMAT will enable intelligent tribological materials characterisation, offering all services described in 2.1. To do so, a new Legal Entity operating as the Services Provider will be set up by ANSYS-GRANTA and ATOS experts in materials and artificial intelligence as well as by four of the most competent European tribology centres, AC2T, BAM, VTT and TEKNIKER.

To achieve the overall success of i-TRIBOMAT, besides the technical activities, an effective stakeholder engagement has been established with the relevant players of the **European Advanced Materials Development Ecosystem** such as (see also **Figure 7.1**):

- The European Technology Platform for Advanced Engineering Materials and Technologies (EUMAT);
- The European Materials Characterisation Council (EMCC)
- The European Materials Modelling Council (EMMC);

For that, a **bilateral link** has been established:

One of the partners, TEKNIKER, is represented in all the bodies, as cosecretary of the EUMAT Platform, as EUMAT representative in EMMC, SC member in EMIRI, and participant in EMMC events. Additionally, AC2T and ANSYS-GRANTA are actively contributing to EMMC and EMCC.

On the other hand, relevant representatives of these bodies take part in the **External Advisory Board (EAB)**, as well as some industry representatives.

The EAB members are informed about i-TRIBOMAT progress on a regular basis and are invited to attend specific meetings of i-TRIBOMAT at least once a year. EAB should provide a clear feedback to be able to advise on the strategy to further develop i-TRIBOMAT business, towards maximum impact on the market.

To support project partners in customer engagement activities, a Translators Network (TN) of collaborators will be created. This body is specific to i-TRIBOMAT, since

it has not been identified in other test beds already in progress [8], [9].

The Translator Network will spread i-TRIBOMAT value proposition to the industry, especially to SMEs. Translators will capture industry needs and translate them into tribological characterisation workflows that will be covered by the i-TRIBOMAT services catalogue. The Translators can be partners or third parties well trained and supported by the project partners. For the sake of transparency, an open call mechanism will be implemented for external translator's recruitment. The Translators Network will be built up in the third year of the project (2021).

To maximise the impact of the Translators' Network, two different translator profiles will be selected and trained:

- Tribology experts who "translate" the meaning of the services that might be provided during the development of a material or product
- Business consultants who communicate the benefits of a European-wide operating Open Innovation Test Bed (OITB).

The channels that Translators may use to approach customers will be relevant fairs, congresses, workshops with companies, webinars, personalized training courses and end-user's meetings. The TN will be especially active once i-TRIBOMAT Open Innovation Test Bed (OITB) is launched. Therefore, Translators activity will continue beyond the duration of the project. The i-TRIBOMAT project has defined three industrially relevant Use Cases representing three different sectors, i.e. transport (Toyota Motor Europe NV), energy (Moventas Wind Oy) and manufacturing (Trygonal Iberia S.L.). These use-cases involve a wide spectrum of bulk materials and coatings, such as steel, polymers and composites. These three use cases will test and validate i-TRIBOMAT services for tribological materials characterisation and the rules and protocols for sharing the infrastructure to ensure fluent and equal operation of the crossinstitutional shared infrastructure.

On top of that, i-TRIBOMAT has designed a "proof of concept" exercise before the OITB is launched. In early 2022, an open call will be conducted to select the SMEs that will play the Early Adopters role. The Early Adopters will be i-TRIBOMAT (SEP) first customers. They will test not only the portfolio of services that the OITB provides, but the SEP, the marketing campaigns, the translators network, the dissemination and the communications activities.

The Translators Network (TN) will spread i-TRIBOMAT value proposition, this is the different services that



Figure 7.1: Ecosystem of i-TRIBOMAT

the Test Bed offers to companies, looking forward identifying SMEs willing to take part as Early Adopters. Then the services required by the Early Adopters will be provided by AC2T, BAM, ANSYS-GRANTA, LTU, TEK, and VTT. As these services are trials and primarily aimed at providing room for service improvements, the Early Adopters services will be financed within the limits of the project budget.

7.2 Prospects

i-TRIBOMAT will ensure an effective stakeholder engagement with and between all relevant players of the European Advanced Materials Development Ecosystem through the different activities defined. Accordingly, the Translators Network and External Advisory Board – representing the valued driven community will be constituted.

In addition, paving the way towards the OITB sustainability, the Early Adopters will be involved at the end of the project to validate i-TRIBOMAT the different services that the Test Bed will offer to companies.

8 Summary & Outlook

This paper was originally presented for the special session on i-TRIBOMAT at 22nd International Colloquium Tribology, describing the progresses during the first year in the European Union’s Horizon 2020 research and innovation programme. Now, emphasis is laid on the development of a unique digital service for tribological characterization of materials. i-TRIBOMAT enables smart R&D in material characterization and design for

all tribology applications. The digital tools from i-TRIBOMAT are versatile and powerful, especially for lab-to-field up-scaling purposes. Moreover, i-TRIBOMAT offers a tailor-made “digital tribo-ware” exclusively for tribology systems of today and tomorrow. i-TRIBOMAT is a sustainable project that keeps on with improvements after the European support ends in 2022. It stays open-minded for collaboration to develop new digital services.

The feedback during the panel discussion will enforced i-TRIBOMAT consortium to deliver customised solutions fitting the needs of end users. i-TRIBOMAT sincerely welcomes your comments, opinions, or requirements to i-tribomat@ac2t.at.

Author contributions:

The original synopsis for 22nd International Colloquium Tribology was written by the speaker of each chapter in collaboration with work package members: chapter 1; Pirker, chapter 2; Alberdi, Benedicto, Bayón, Pagano, and Bravo, chapter 3; García, Grundtner, Spaltmann, and Gradt, chapter 4; Kogia, Dykeman, and Liedtke, chapter 5; Ronkainen, Majaniemi, Cihak-Bayr, and Heino, chapter 6; Minami, Nyberg, Vernes, Soivio, Gkagkas, and Mont, chapter 7; Igartua, Alonso, and Amigorena, chapter 8; Tóth.

The final manuscript was edited and compiled by Spaltmann, Majaniemi, Alberdi, Alonso, Pirker, Tóth, and Minami.



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