FRONT PAGE

PROJECT FINAL REPORT

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Project acronym: T-REX

Project title: "LIFECYCLE EXTENSION THROUGH PRODUCT REDESIGN AND REPAIR, RENOVATION, REUSE, RECYCLE STRATEGIES FOR USAGE&REUSAGE-ORIENTED BUSINESS MODELS"

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4.1. Final publishable summary report

4.1.1. Executive summary

New trends for manufactures producing and selling durable products pushes towards, as a way to differentiate or as an order qualifier, not to sell the products but rather to sell its usage or its performance. What companies are moving towards is not the sales of a product, but of a Product-Service System, where the service components may be predominant with respect to the product one. Such new Business Models completely change the manufacturer's perspective over the costs and revenues arising during the product lifecycle. In order to maximize its profit, manufacturers should (re)design the products and their related services to achieve the minimum Life Cycle Cost, by for instance extending the product lifecycle or reducing products usage and/or maintenance costs, even at the expenses of higher costs related to materials, production, processes and/or supporting technologies. New Business Models that do not transfer product ownership, therefore offer an opportunity to redesign the products, the related (after-sale) services, and the (after-sales service) supply chain. In fact, in the new Business Model all the costs arising in the entire product lifetime, from early conception to disposal, are suffered by the manufacturer and must be covered by regular user fees, according respectively to the product usage or performance in field.

T-REX project is funded by the European Union and addresses the **development of usage-oriented Business Models** in the domains of Transportation, Machinery and Automation. In these new Business Models the sales of the product is substituted by the sales of its usage (e.g. renting, pay-per-use), or its performance or outcomes (e.g. pay-per-performance). This new trend is fuelled by an increased emphasis on the service business in capital goods industries.

Consequently, T-REX promotes the development of **integrated Product-Service Systems (PSS) and new business solutions**: a shift from value in exchange to value in use for customer needs satisfaction. Companies and supply chains should focus on reducing the Total Cost of Ownership of the products or PPS, and on extending their lifecycle to maximize profits, but also to increase customer utility and the lifecycle value of their offerings.

The objective of T-REX has been to develop conceptual tools to implement and experiment, through three industrial application cases, **a new business platform for the offering of capital goods as new Product-Service Systems**, whose main elements are:

- A new **Service-Oriented Business Models** (SOBM) reference framework, that supports the identification and development of such Business Models suited for the change in the way that products are offered and customer relationships managed.
- An improved design of the products by the adoption of the **Design for X** (DfX) approach, that supports the identification and development of design actions to extend the lifecycle, to foster upgrading and renovation, and to support serviceability of products, consistently with these new Business Models.
- The re-engineering of traditional support services by using **Service Engineering** (SE) techniques to improve new or existing services, consistently with these new Business Models.
- The increasing of product availability and the reducing of the Total Cost of Ownership by developing **Condition based Maintenance** technologies and a **Fleet Management** platform (CbM & FM) which will integrate local Condition Monitoring capacities and Assets Health Management customizable to the industry requirements.

As result, **three practical demonstrators** in the Transportation (forklift trucks), Machinery (machine-tools) and Automation (robot solutions) have been developed, experimented and validated. These demonstrators have shown that through the new business platform it is possible to create new Service-Oriented Business Models that can achieve up to **84% of component re-use**, a **lifecycle extension in the range of 30-100%**, and a **reduction of maintenance service costs by 27-36%**, which can be translated into **11 to 50% of savings on Total Cost of Ownership**.

4.1.2. Summary description of project context and objectives

The current economic downturn and the global economy competitiveness are pushing many sectors related to manufacturing industry to adapt to an ever-changing business environment looking for new ways to diversify their business. In particular, there is a trend for manufacturers producing and selling durable products towards selling the usage of the product (e.g. renting, pay-x-use), or even selling the product performance or outcomes (e.g. pay-x-performance). In response to these drivers, new trends have emerged such as the 'servitization' of manufacturing. The servitization can be also seen as a Business Model innovation of organizations processes and capabilities wherein manufacturing companies make a shift from selling product to selling integrated products and services, with the aim to satisfy customer needs, enhance the company performance and achieve competitive advantage.

Despite this, a limited application of "Service-Oriented" Business Models has been observed in the capital goods sectors, especially within Small and Medium-sized Enterprises (SMEs). This is due also to the lack of such Business Model based approach that guides companies in the servitization process. These new Business Models completely change the manufacturer's perspective over the costs and revenues arising during the product lifecycle. The relevance of concepts such as Total Cost of Ownership, lifecycle extension or maintenance management strongly increases, and thus the control of costs related to the product usage and maintenance is mandatory in order to achieve a profitable business, even at the expenses of higher costs related to materials, production, processes or supporting technologies. Therefore, there is an important organizational and technological change requested, and this is why there is still today a limited diffusion of these new Business Models, especially on manufacturing SMEs. This is an important change, and despite the expected benefits, the transition towards such models is slow and mainly concerning large manufacturers and multinationals. Smaller firms often lack managerial vision, competence and resources to revolution their Strategy, Organization (internal and inter-firm), Product Design, Maintenance/Repair/Renovation Services and Economic Performance Measurement Systems (towards customer lifetime value). Frequently capital goods manufacturers act as pure suppliers of pieces of equipment while they neglect the opportunities stemming from a more service-oriented approach. Thus, they tend to lose control over their installed base, and therefore lose the opportunity to offer additional customized services and products.

The aim of T-REX project has been to develop and prototype specific technologies and tools, through three business application cases, as 'levers' for the implementation and experimentation of **a business platform for the offering of capital goods as new Product-Service Systems (PSS)**, that will empower the companies (specially SMEs) with:

- A new **Service-Oriented Business Models (SOBM)** reference framework that changes the way products are offered and customer relationships managed.

- An improved design of the products by the adoption of the **Design for X** (DfX) approach, to extend the lifecycle, to foster upgrading and renovation, and to support serviceability.
- The re-engineering of traditional support services by using **Service Engineering** (SE) techniques to improve new or existing services.
- The increasing of product availability and the reducing of the Total Cost of Ownership by developing **Condition based Maintenance** technologies and a **Fleet Management** platform (CbM & FM), Integrating local Condition Monitoring capacities and tools for Asset Health Management customizable to the industry requirements.

The **specific industrial objectives established from the beginning of the project** through the application of the new business platform **on the three practical demonstrators**, in the Transportation (forklift trucks), Machinery (machine tools) and Automation (robot solutions) domains, were:

i.) Reduce operational maintenance service cost by 15%-30%

ii.) Re-use components for 55-70% depending on the product, and

iii.) Extend the lifecycle of 30-80% depending on the product or components.

iv.) All of these contribute to reductions in the Life Cycle Cost in the range of 25-30%.

As result, the experimented and validated **three demonstrators** in forklift trucks (ULMA), machine tools (FIDIA) and robot solutions (KINE) have shown that through the new business platform it is possible to create new Service-Oriented Business Models that can achieve up to **84% of component re-use**, a **lifecycle extension in the range of 30-100%**, and a **reduction of maintenance service costs by 27-36%**, which can be translated into **11 to 50% of savings on Total Cost of Ownership (TCO)**.

INDICATOR	DESCRIPTION	T-REX OBJECTIVE	ULMA	FIDIA	KINE
LIFECYCLE EXT. (%)	PRODUCT LIFE EXTENSION	30%-80%	**100,0%**	**33,3%**	**33,3%**
RE-USE INCREASE (%)	NET VALUE GENERATED RE-USING THE PRODUCT IN RELATION WITH THE ORIGINAL INVESTMENT	55%-70%	**84,2%**	**50,4%**	**60,1%**
MAINT. COST REDUCTION (%)	REDUCE OPERATIONAL MAINTENANCE SERVICE COSTS IN RELATION WITH THE ORIGINAL INVESTMENT	15%-30%	**36,7%**	**34,8%**	**27,3%**
LCC / TCO REDUCTION (%)	TOTAL COST REDUCTION (WITH RE-USE + MAINT. COST + LIFECYCLE EXT.) IN RELATION WITH THE ORIGINAL INVESTMENT	25%-30%	**11,9%**	**35,7%**	**50,5%**

4.1.3. Description of main S&T results/foregrounds

Main project results have been characterized from a holistic approach taking advantages of the synergies between technological and industrial partners to set up **five Global Key Exploitable Results**, named **KER G1 to G5**, plus another three particular exploitable R&D results named KER3.2, KER 4.2 and KER 5.2.

KER G1: Service-Oriented Business Modelling (SOBM) process and toolset

This result concerns to the creation of new Business Models, and in particular to the new Service-Oriented Business Models (SOBM) reference framework deployment. It offers **a methodology to support companies at developing SOBM for new Product-Service Systems (PSS)** implementation by using sequential steps, guidelines and practical tools (see Figure 1).

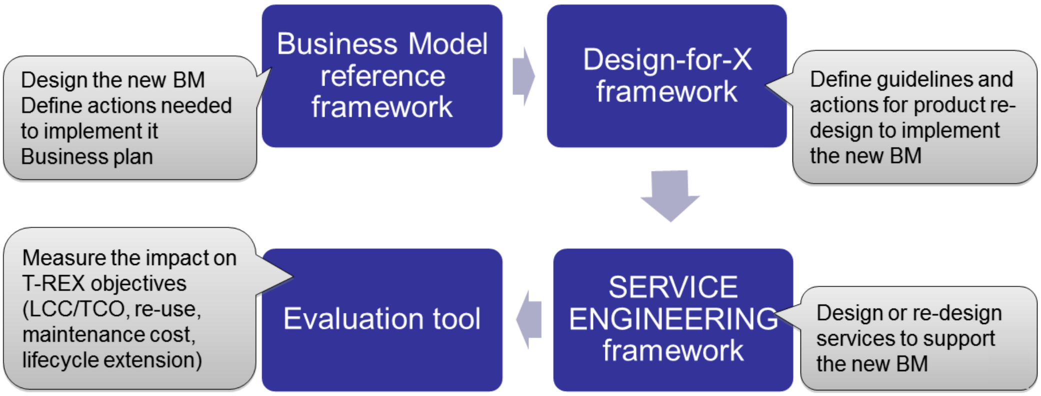

Figure 1: Service-Oriented Business Modelling process and toolset

The KER G1 exploits the T-REX **SOBM reference framework**, which is based on three levels:

- LEVEL 1: a description of five archetypes of Business Models that reflects different degrees of service orientation (**5 Business Model Typologies**, see Figure 2).

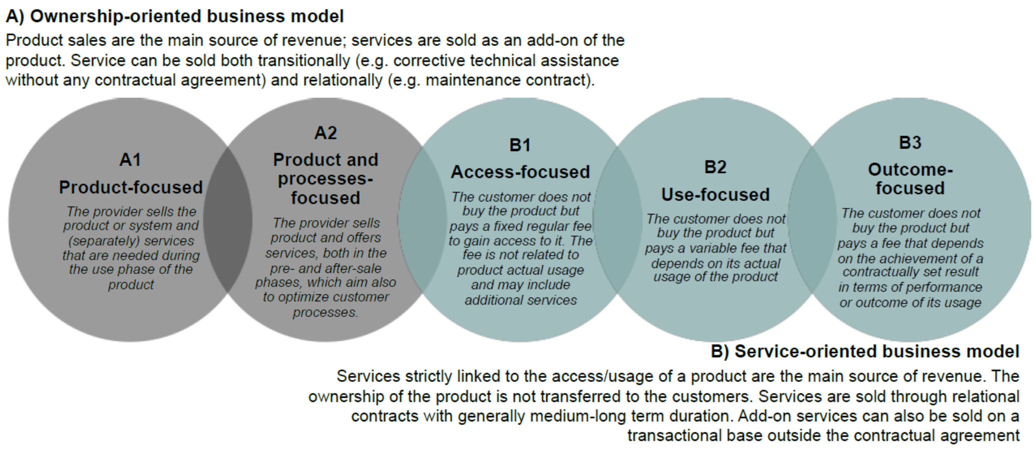

Figure 2: the five Business Model Typologies (service orientation)

- LEVEL 2: a process model that points out the steps to be followed by a company in order to define and plan the new Business Model (**Business Model Innovation Process**).

- LEVEL 3: some tools that can guide companies through the steps of the Business Model Innovation Process, towards the implementation of the new Business Model (**Innovation Methods & Tools**).

This result includes complementary reference frameworks named **Design-for-X (DfX)** and **Service Engineering (SE)** to describe the typologies, innovation processes and related methods and tools needed to improve integrated products and services associated to the existing Business Models when facing a comprehensive SOBM transition.

Four selected DfX typologies (Reliability, Serviceability, End-of-life and Lifecycle), as well as four scenarios for the (re-)engineering of services (redesigned services for existing markets, redesigned services for new markets, new services for existing markets, new services for new markets) will be the basis to reach the four goals of T-REX project: extend product lifecycle, increase reuse, decrease maintenance costs, and consequently improve the Total Cost of Ownership.

All these steps towards a successful transition to new SOBM will be assessed through the use of a novel **Evaluation Tool**, specifically developed for a quick preliminary evaluation of the concepts and a comprehensive final validation of a whole Service-Oriented Business Model transition.

KER G2: Platform and tools for an easy to deploy Predictive Maintenance (PdM) solution for Fleet-Wide Asset Health Management (FW-AHM)

The **Fleet-Wide Asset Health Management (FW-AHM) platform** is supported by **Condition based Maintenance (CbM)** technologies, including **Condition Monitoring (CM)** and the **Fleet Management (FM)** software KASEM® (see Figure 3).

This platform offers, as a key innovation point, **a methodology that allows identifying the best maintenance strategy** to be applied according to customer objectives, constraints and preferences, which leads to a **fast deployment of Predictive Maintenance (PdM) solutions** for FW-AHM. The methodology links the business perspectives (e.g. financial, reusability, maintenance) with technical objectives (e.g. usage, condition, performance) and specific indicators and variables linked to each use case, at the same time that facilitates the choice of appropriate hardware to support the local Condition Monitoring.

To support the deployment of the PdM solutions, a distributed architecture based on easy to deploy low cost devices has been defined and tested. The FW-AHM platform distributed architecture includes standard local monitoring algorithms & software to be embedded in different hardware solutions depending on the range of complexity and performance requested.

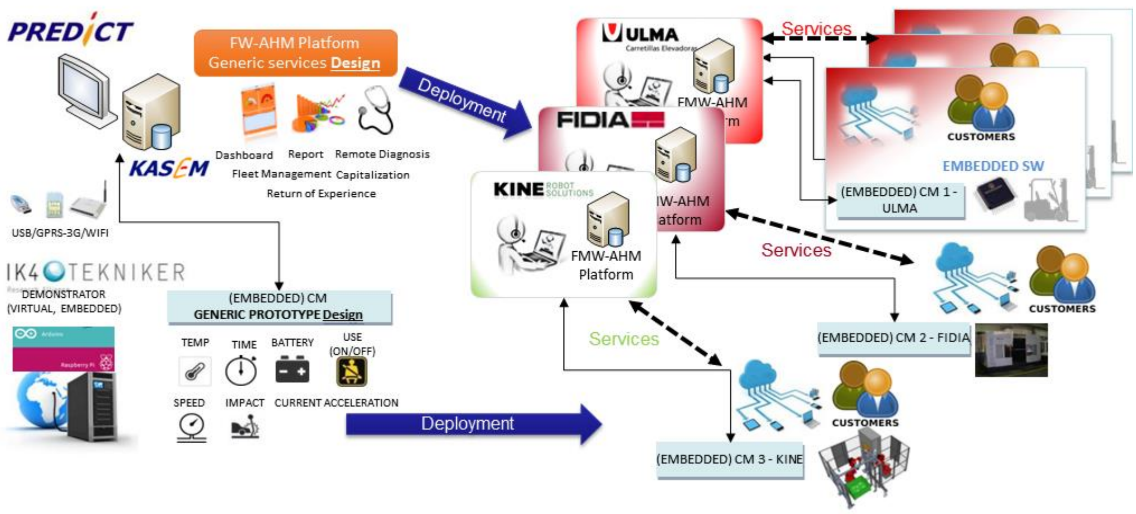

Figure 3: Fleet-Wide Asset Health Management (FW-AHM) platform distributed architecture

Individual **local Condition based Maintenance (CbM) modules** are then connected to a remote **Fleet Management (FM) module KASEM®** with enhanced features (data collection, storage, usage, performance, health assessment and remote diagnostic).

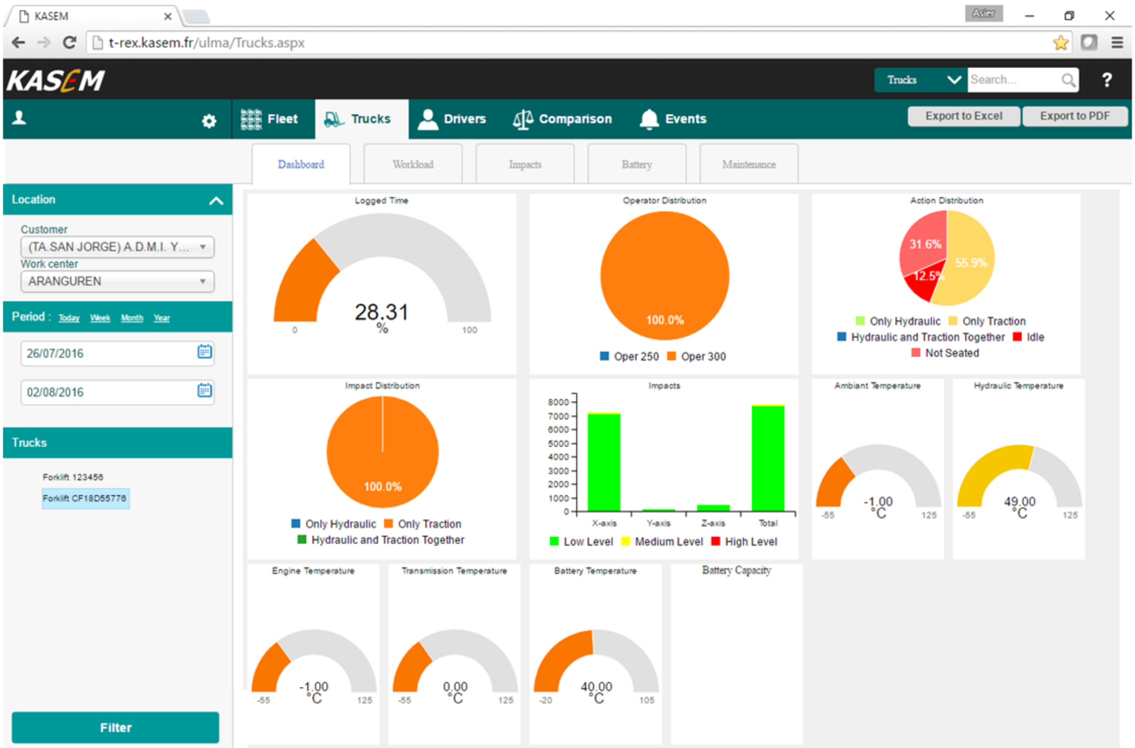

Figure 4: General dashboard for Fleet Management

The FW-AHM platform support innovative features and technology to provide fleet-wide monitoring, diagnostic and health management services, to deliver the required data and information for the operational and related maintenance strategy optimization services.

KER G3: ULMA Fleet Manager (Service solution offering an integrated platform for Condition based Maintenance and Fleet Management)

This result offers to customers a service package made of an **embedded monitoring hardware** that collects essential data from forklift trucks, and other equipments in the Transportation sector, for the **Condition based Maintenance (CbM) service**. The input data is comprised of several signals and comes from sensors over the whole vehicle, as well as from certain components like the battery which has been enabled with a datalogger to monitor its level of charge or its temperature. The embedded monitoring hardware is composed of several embedded modules for signals capturing, for decision taking (health assessment) and for communication with external devices, including the integration with other components dataloggers.

The package is also made of a **software remote platform** where this information is displayed and exploited at manufacturer / dealer / end user level, i.e. the Fleet-Wide Asset Health Management (FW-AHM) platform by means of KASEM® software (see Figure 5), which also provides integration capabilities with the Enterprise Resource Planning (ERP) software at the company to gather the maximum possible information for the **Fleet Management (FM)**.

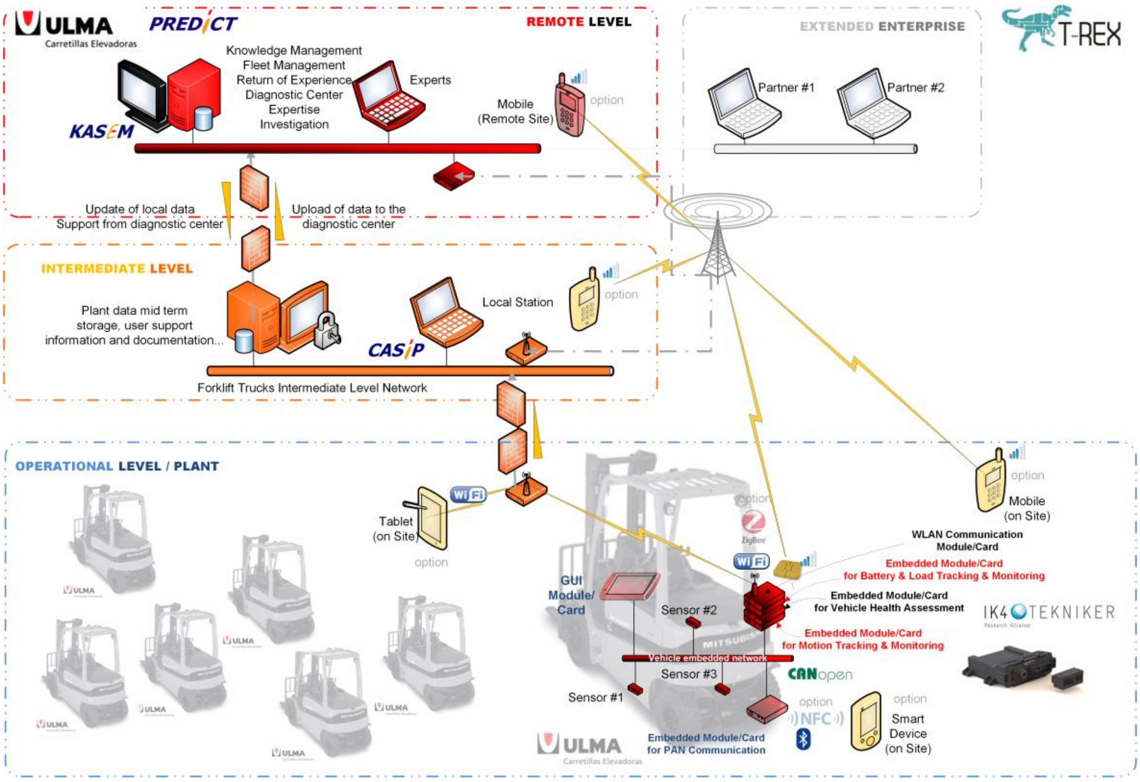

Figure 5: Condition based Maintenance (CbM) and Fleet Management (FM) architecture

As differential factor, both embedded monitoring hardware for CbM and the software remote platform for Fleet Management include some "knowledge algorithms" to provide **predictive functionalities**. No other commercial monitoring systems have this feature that allows a fast local actuation over the vehicle (e.g. stop the forklift truck after a strong collision or when possible danger for the engine), and experience capitalization and knowledge management at fleet level to support remote diagnosis and health assessment.

KER G4: Service solution of Condition based Maintenance (CbM) for new generation machine tool electro-spindles

The overall solution proposed exploits the features of **a new electro-spindle** that has been re-designed from high performance and high reliability driven approach, and for Condition Monitoring in practical applications. The new electro-spindle has been equipped with a set of sensors that allow machine tool manufacturer to retrieve essential data about the working and operating conditions of the component.

The solution has been supplemented with the development of a new Computer Numerical Control **(CNC) software application** that allows a machine tool to perform some automatic tests at the same time that collects data from the field operation and transmit it via FTP to a remote server managed by KASEM® software for the Fleet-Wide Asset Health Management (FW-AHM) platform. This platform enables the company to offer its customers **a new Condition based Maintenance (CbM) service** (see Figure 6).

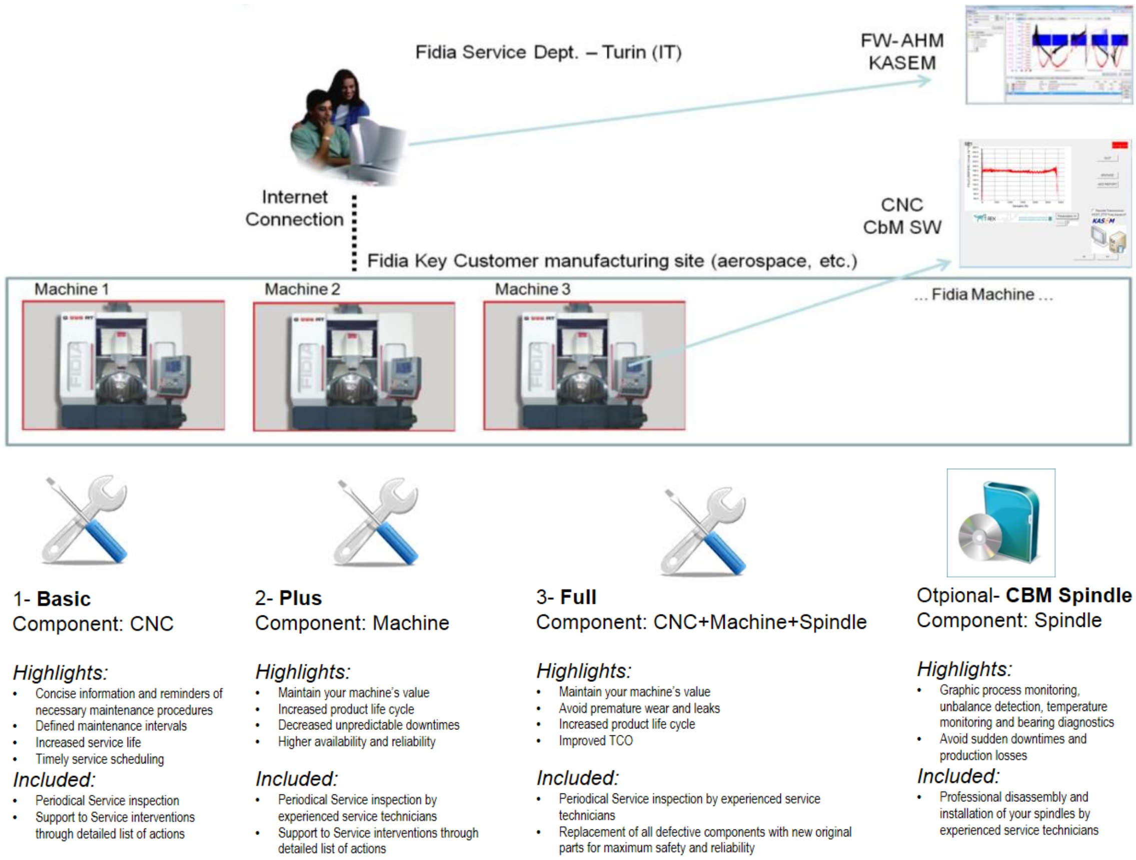

Figure 6: Condition based Maintenance (CbM) solution for machine tools

Servitization throughout the lifecycle of the machine tool, by means of various preventive and emergency services offered will be extremely effective in maximizing uptime and maintaining customer machines' capabilities.

Predictive capabilities provided by this new service to detect anomalies or incipient breakages (such as unbalance, bearings, tool damage, windings problems, etc.) improve machine tool productivity avoiding sudden interruptions in machining of workpieces due to unexpected breakdowns, which in turn increases machine tool availability and lowers Total Cost of Ownership (TCO) for customers.

KER G5: Service solution of Condition based Maintenance (CbM) for Robot and Automation Systems

The **new KINE's Business Model** has two main product options:

1) **traditional robot system** deliveries with and without additional maintenance service;
2) new **service-oriented robot system** deliveries with included maintenance service and optional operation service.

In the new Service-Oriented Business Model, **KINE owns the system** instead of the customer. In particular, the customer pays periodically a fee determined by the usage or performance of the system. The new Business Model product and services options are summarized in the Figure 7.

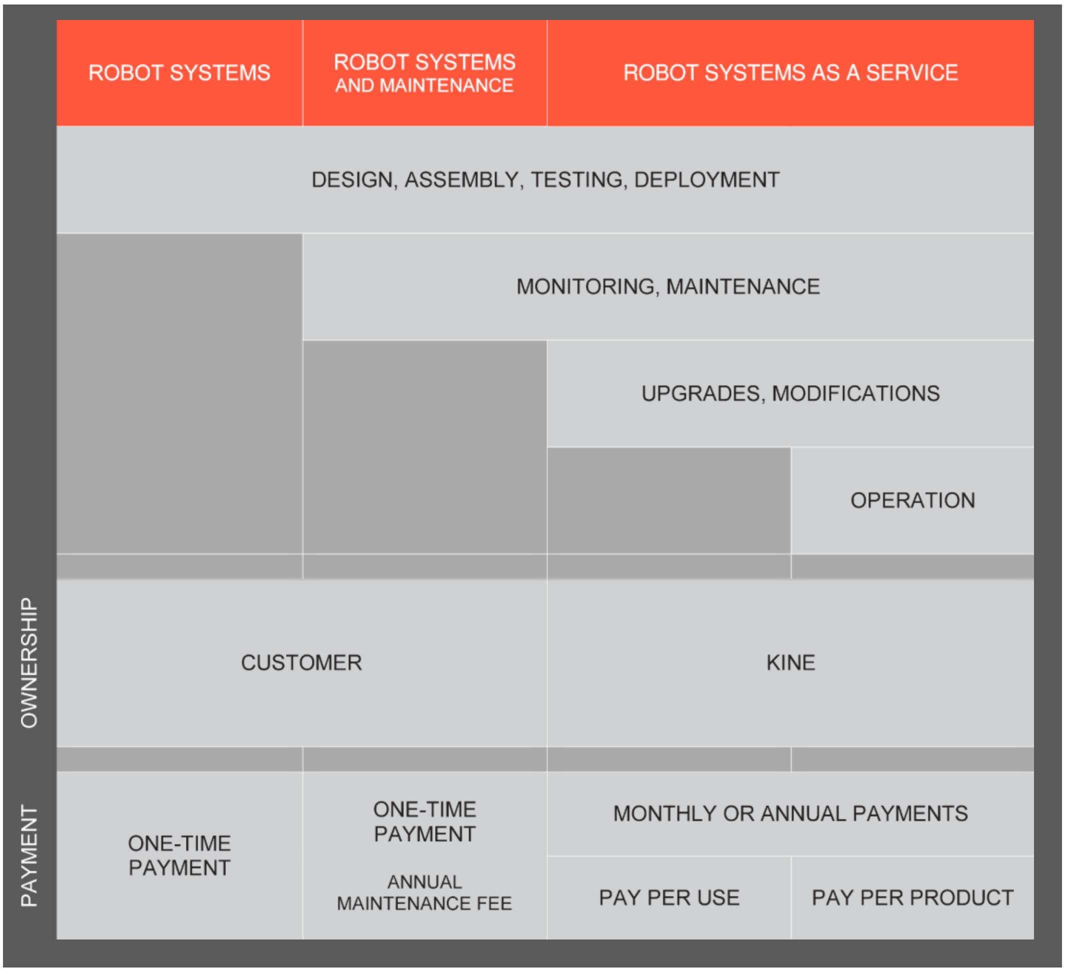

Figure 7: Summary of the new KINE's Business Model

This new SOBM is supported by a **new datalogger hardware & software** solution developed for gathering data from virtually any electronically controlled device or system. The modular and easily customizable datalogger device will decrease systems downtime by applying Condition Monitoring (CM) for Condition based Maintenance (CbM) instead of the traditional scheduled Preventive Maintenance. For the **new Condition based Maintenance (CbM) solution** for complex robot solutions at KINE there were developed a data acquisition system, a data analysis system and a remote management system. Additionally, data was collected from a single robot solution (OKMETIC: PESUPENKKI), visualized and then analyzed using dedicated tools. Some of the monitored functional faults are listed in the Figure 8.

Functional failures	Indicators	Formula	Parameters
Crash or broken wafers	Robot movement variability and unexpected stops	Statistics for variability	Robot force, position and rotation (XYZ)
Reduced performance	Picks and drops per hour	Statistics for variability	Pick, Drop
Controller overheating	Controller temperature levels and variability	Statistics for variability	Controller and CPU temperature
Wear	Hours of use		Robot uptime

Figure 8: Robot solution Condition Monitoring table

The longer the system is up and running, the higher the income will be. Consequently, the customers will be more satisfied. While some customers run their systems only for half a day, some customers need to keep the systems up and running 24/7, and in those cases Condition Monitoring is critical and providing predictions for the future conditions of the system, based on the collected data, is mandatory.

The Condition Monitoring system consists of a **datalogger device with software** that receives data from industrial automation equipment and sensors (through a Stäubli robot in this case) and sends it through a TOSIBOX gateway (with optional 4G modem) to PREDICT's KASEM® platform and KINE's own servers in cloud for storage, processing and visualization. KINE used TOSIBOX for connecting securely to its robot systems to run remote diagnostics and software modifications on them. Figure 9 summarizes the structure of the demonstrated Condition Monitoring system.

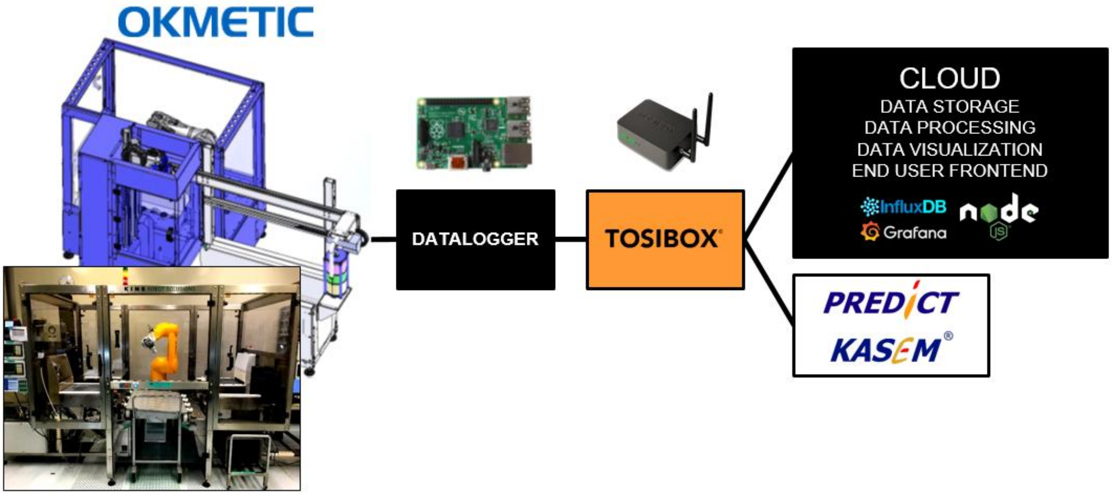

Figure 9: Condition Monitoring system

Simply collecting data has no value, therefore **visualizations and reports** are needed. PREDICT provided reports generated by their KASEM platform, showing its potential as a tool for our customers on how they could improve their production processes further. The powerful data visualization tools used internally by KINE have proven highly useful for analysing problems and finding solutions to them with ease. Currently, KINE uses these technologies in extremely physically demanding environments and has gain much insight and know-how on how to use the tools efficiently to keep its systems up and running 24/7.

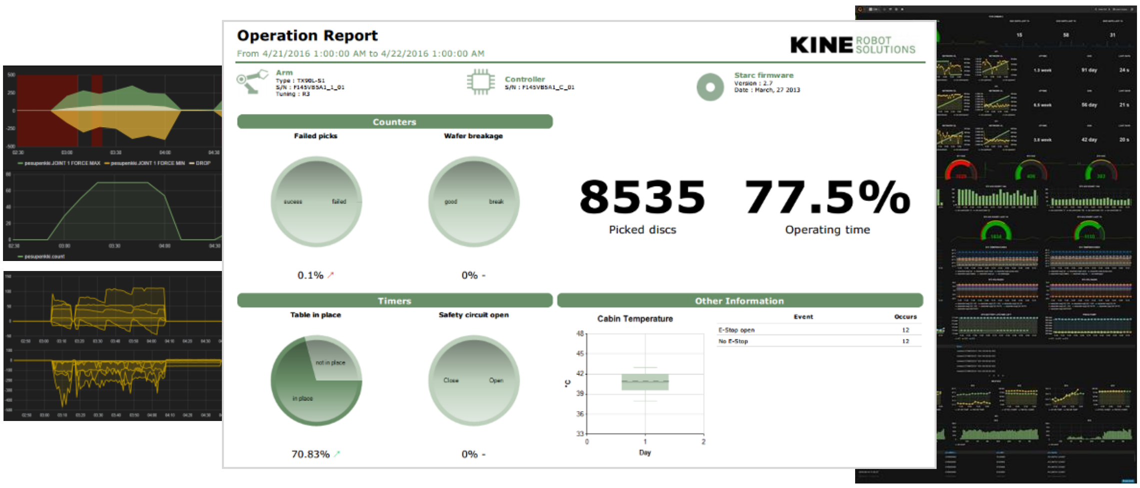

Figure 10: Condition Monitoring visualization and reporting

KER 3.2: Fleet-Wide Asset Health Management (FW-AHM) platform (PREDICT)

For the purpose of Fleet Management within each application domain, **elementary services** have been developed and composed in order to **provide generic and modular fleet-wide monitoring and management** features. Elementary services, data acquisition and storage, processing and reporting are depicted in Figure 11. Collected data on systems are sent to the FW-AHM platform. Data can come from different sources and be of different types. In the platform point of view, data are stored into their respective system's knowledge base. Then, for each system, the **platform processes collected data** in order to compute system's elaborated variables and indicators. When one user requires information about a fleet or a sub-fleet of systems, the remote **platform aggregates system indicators to build fleet synthetic indicators**. Aggregation results are then presented in a static or dynamic dashboard.

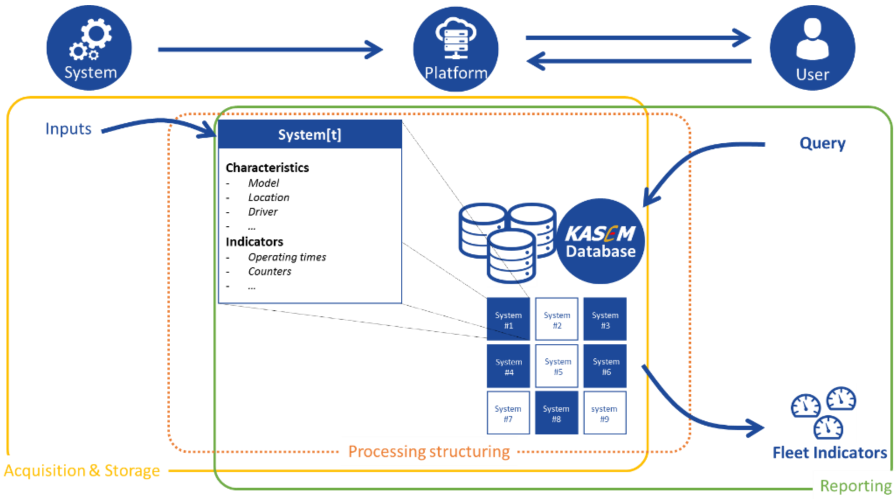

Figure 11: Fleet-wide management services architecture

One of the most contribution of this task is the development of KASEM® **algorithms** from a generic point of view, i.e. independent of application domain. These data processing algorithms can then be composed to compute health indicators of a sub-system, a system or a fleet. Data processing algorithms are classified in four categories as shown in Figure 12.

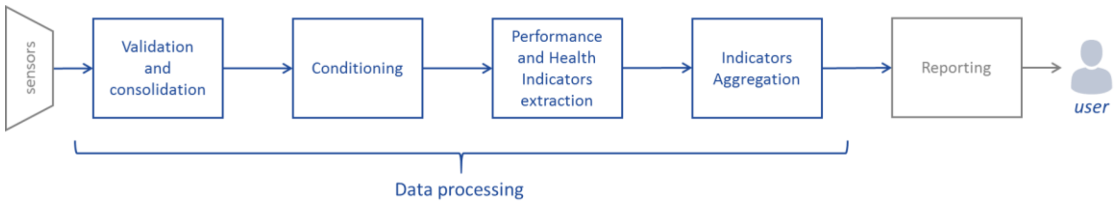

Figure 12: From raw data to reporting

User oriented services, i.e. Operation and maintenance services, can be for a general manager of a fleet a dashboard of all the systems' business indicators, or for a technical manager a dashboard of all the systems' maintenance and health status. At the bottom level of the pyramidal hierarchy, a technical operator, should have a fast overview of the systems status and should be alerted at the right time when a system needs to be checked. FW-AHM platform **needs in term of advanced services** can be summarized:

- **Data Visualization service:** gather all the tools and ways to communicate a clear and efficient information to the users (statistical graphics, plots, information graphics, tables and charts) and to help users to analyse and reason about data. It aims at making complex information more accessible, understandable and usable.

- **Event management service:** gather all the tools and ways to generate events relative to systems' status (fault detection, prognostics, health) and to manage these events (validation, cancellation).
- **Analysis and Investigation service:** gather all the tools and ways to analyse, and help to understand events and to take the good decision. It regroups all the possible actions that help to identify what causes an event.
- **Knowledge sharing service:** gather all the ways to create and consult system's documentation and information.

Most of the development have been focused on the data visualization service, because this is the service in charge to make the connection between users and FW-AHM platform. **According to use case reports or dashboard have been designed**.

For Transportation, specific web application has been developed. This application is composed of several dashboards allowing to share indicators knowledge for a forklift truck, a driver, a fleet of forklift trucks or a fleet of drivers. Some screenshots of this application are depicted in Figure 13.

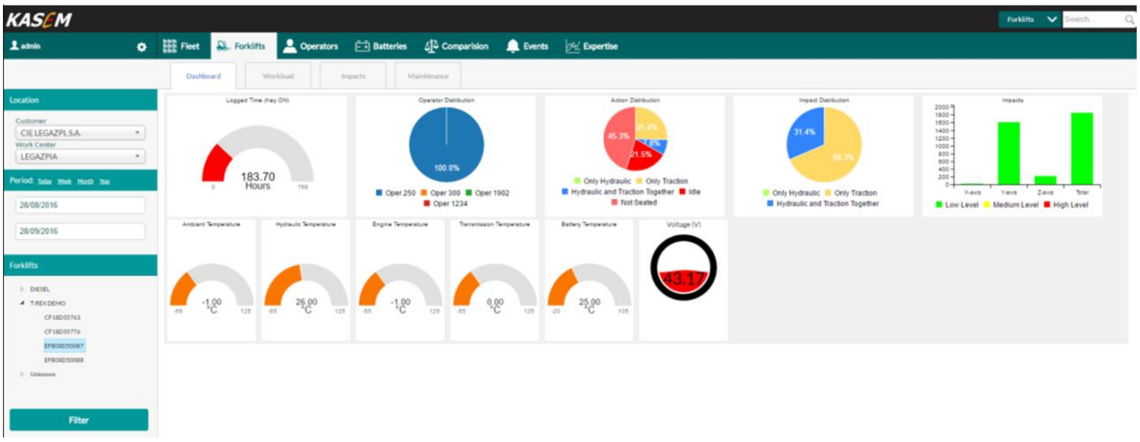

Figure 13: Forklift trucks dashboard

For machinery domain, a mobile application has been developed to display synthetic of machine tools fleet health and facilitate predictive maintenance everywhere. Some screen captures are shown and explained in Figure 14.

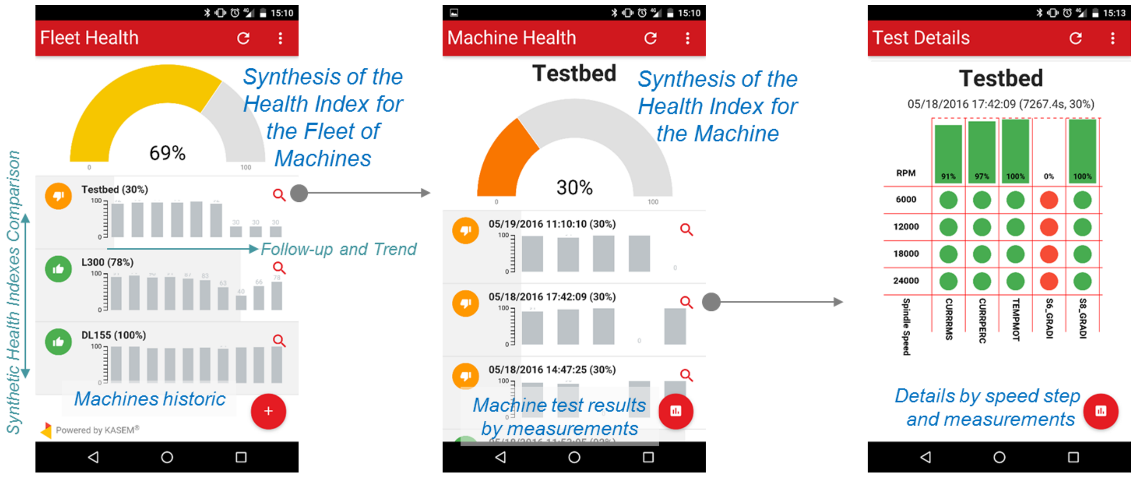

Figure 14: Machine tools, Fleet-Wide tests session follow up apps.

For Automation use case, an operation report has been designed to present production statistics during a working period as depicted Figure 15.

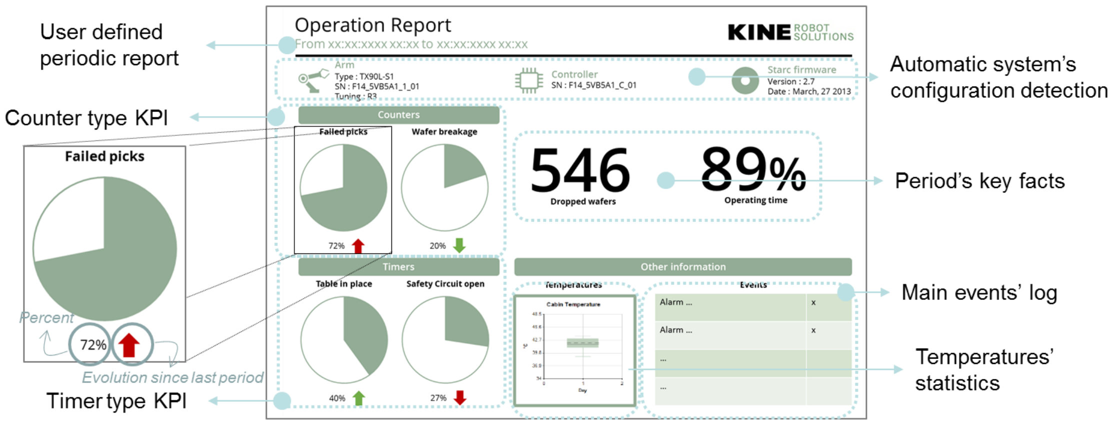

Figure 15: Robots, periodic operation report.

KER 4.2: Batteries sulfatation restrain (by pulses) and on-line monitoring embedded hardware (ESENERGIA Pulse)

A battery can store and deliver energy through interaction between the plates and the acid. In theory, the batteries should last for several years, but usually its useful life is shorter. Even in new batteries, after each charge and discharge process of the battery there is a capacity lost. This happens because of the problems caused by sulfation. A first **adaptive electronic battery regeneration (Pulse) and monitoring prototype has been developed** and tested by ESENERGIA on forklift trucks batteries.

This embedded device contains the **Pulse technology** to avoid battery sulfatation and to extend its lifecycle. An independent 3rd party **study of the benefits of the pulse** was performed comparing several types of batteries charges and discharge cycles, with and without the pulse technology. One of the results of this study is presented in the Figure 16.

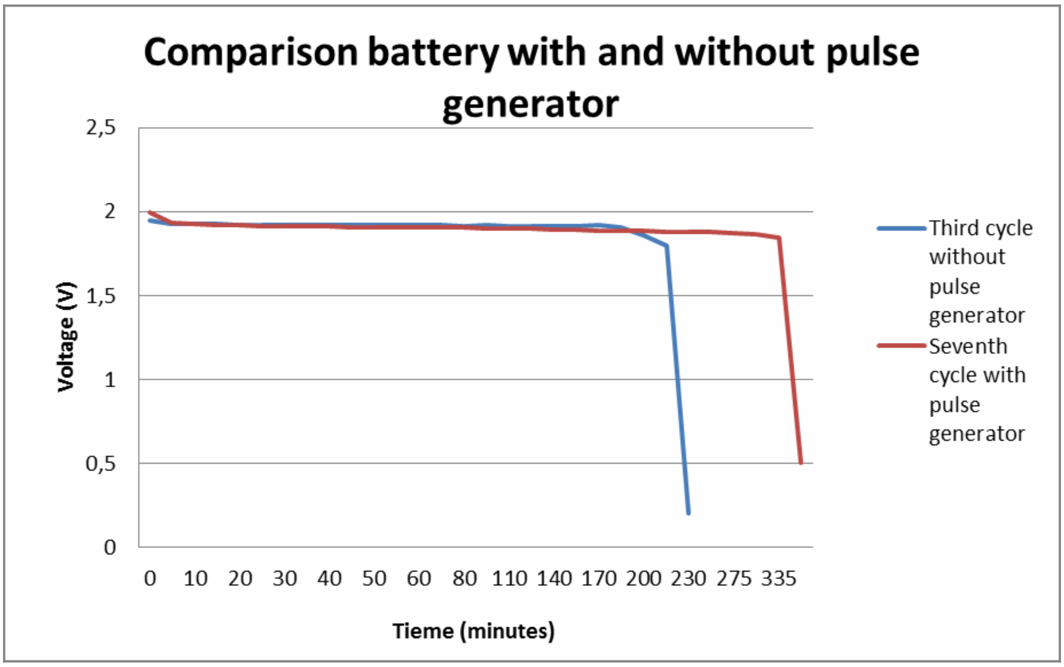

Figure 16: Comparison of a battery with and without pulse technology.

From this Pulse technology, the challenge was to design **a Battery Pulse device** easy to connect to vehicles' batteries, and which in turn gave also information for the batteries monitoring like the following:

- Voltage measurements: the batteries have normal working voltage ranges, and below these ranges the efficiency and durability of the battery decreases very fast.
- Current measures: consumed current can be used to predict the durability of the battery as well as to detect the beginning of the charging and discharging cycles. Other information that can be obtained from current measures is the battery capacity.
- Temperature control in the core of the battery.
- Electrolyte level control: the lack of the required electrolyte level is the main factor that may dramatically reduce the capacity and life of the battery.
- Number of cycles of charge/discharge, including deep discharges which indicates that the battery is correctly used.

Figure 17: ESENERGIA Pulse device

Also the communication of such information to external systems like a technician laptop / Smartphone or to a Fleet Management platform was set as a requirement for ESENERGIA Pulse device. These have been achieved by **USB and Bluetooth connection functionalities**. Likewise, **a dedicated monitoring software** has been developed for the Battery Pulse device.

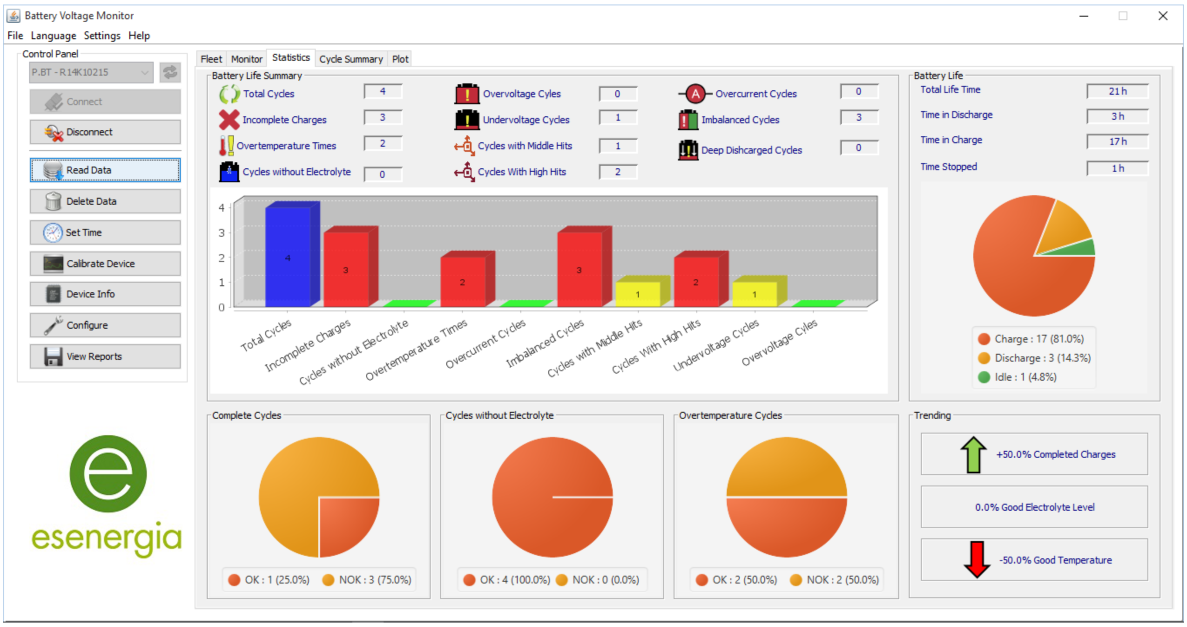

Figure 18: ESENERGIA's battery monitoring software

As conclusion, with the new ESENERGIA Pulse device the batteries can be protected through the elongation of batteries lifespan by keeping the electrolyte level with a higher concentration, the regeneration of the electrolyte by reducing the lead sulphates in the electrodes from batteries already suffer from sulfation, the collection of information about battery operational conditions and finally through the users' information about bad habits. Also with the new Battery Pulse device it can be protected the environment and saved money by reducing the amount of batteries charges by half, by lowering the charging power consumption and by improving the vehicle productivity.

KER 5.2: High Performance and High Reliability new Electro-Spindle (IMATECNO)

The growing rotational speed of current electro-spindles imposes progressively growing machining precisions, more and more sophisticated components use and increasingly accurate machining operations, monitoring and controlling. Upper class high speed milling machines and machining centres are now equipped with spindles up to 50.000 rpm. This speed range lead to two main failures, failure of rotating unions causing refrigerant and lubricant fluids leakage, and damage at the bearings due to vibrations (unbalanced tools and tool-holders).

Based on a **reliability and maintainability analyses** carried out by IMATECNO (e.g. to collect and list all the reports related to the assistance interventions and then classifying and analysing the failures), an **electro-spindle** has been **redesigned and also equipped with new sensors** (see Figure 19). New available sensors allow the machine tool builder to retrieve more information from the working and operating conditions of the spindle. No manufacturer in the market provides such an extensive range of sensors mounted on the spindle because the design of the new electro-spindle was made to shift **from a purely performance to a reliability driven concept**, also considering the maintainability criteria.

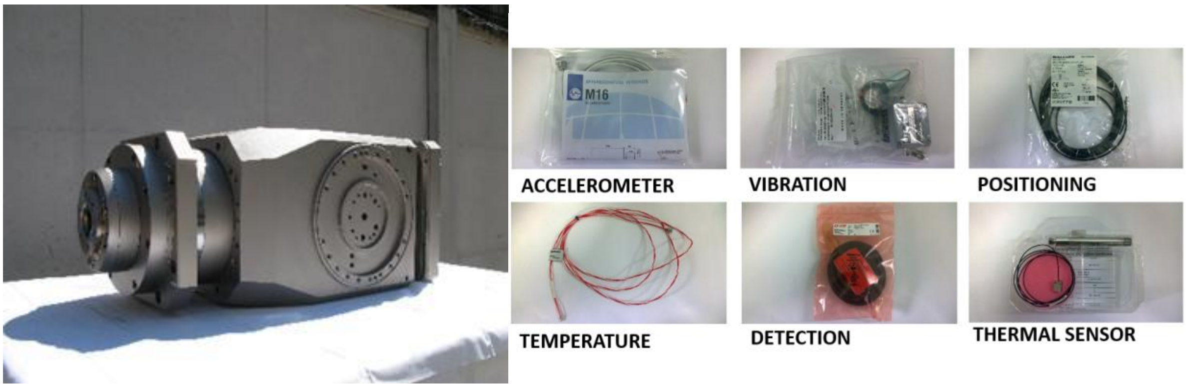

Figure 19: new IMATECNO electro-spindle and its set of sensors

Five main re-design actions have been implemented on a Type 110663A670 – HSK A63 top class electro-spindle regarding:

- Drainage system: addition of a liquid level sensor in order to prevent failures due to seepage of liquids through the distributor.
- Vibrations: acceleration sensor to detect eccentricities and asymmetries of the high-speed rotating parts to prevent bearings damage.
- Temperatures: addition of temperature sensors on the two bearings and a thermal sensor on the motor, together with an analysis to correlate among temperature and expected remaining life of the electro-spindle.
- Draw bar position detection: to monitor the clamping of the tool by the clamps.
- Piston back sensor: to detect the correct position of the back piston in order to allow the rotation after a tool change.

The re-design activities let IMATECNO foresee that final reliability figures result better than expected have been achieved. Main indicators to measure the reliability are the MTBF or Mean Time Between Failures, the MTTR or Mean Time To Repair, which combined can be obtained the system Availability (A %).

Parameter	Foreseen values			c After the analytical Calculation	Delta (a, c)
	a Actual	b Objective	Delta (a, b)		
MTBF	50 days	125 days	+150%	512.81 days	+925%
MTTR	1.04 days	.33 days	-68%	.46 days	-55%
$A_{\%}$	97.96	99.73	+1.8%	99.91	+2%

Figure 20: Reliability estimation and outcomes for re-designed electro-spindle

IMATECNO electro-spindles fully sensorized are already on the market. Electro-spindles like these are, of course, more expensive than those not sensorized, and are for this reason destined to top-end High Speed Milling Machines. New available sensors allow FIDIA machines to retrieve more information from the working and operational conditions of the spindle, and enables the company to offer its customers **a new Condition based Maintenance (CbM) service**.

4.1.4. Potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

(1) MARKET OVERVIEW

In product-service businesses there is a business shift from selling physical products towards providing the client with a mix of products and services, typically in terms of the use or performance of the product.

T-REX project is oriented towards the following three target markets:

- Forklift truck provider
- Machine tool manufacturer
- Robot solutions provider

T-REX promotes integrated Product-Service Systems (PSS) for these three target sectors: Transportation, Machinery and Automation domains. Nonetheless, the final users of a product-service business are these industries' clients.

Worldwide the forklift truck market is dominated by five big companies (two of them European). The recent economic crisis has led to a sharp drop in the Spanish market in 2008 and demand did not increase significantly until 2014. However, a change in customer behaviour has occurred as well. Before the crisis sales and rentals were both common, now rentals far exceed sales. Companies, especially for Small and Medium-sized Enterprises (SMEs), face a restructuring from seller or distributor to rental company as their core business in the near future, but long-term relationships with customers and reliable products are necessary to promote these services.

The European machine-tool market is led by SMEs and is one of the most competitive sectors globally. More than one third of the world machine tool production generates in Europe, and half of world exports originate from Europe. There are about a thousand manufacturers, mostly from Germany, Italy, Spain and France, who employ about a hundred and fifty thousand people. Both the recent economic crisis and Asian countries put pressure to European manufacturers, with a shift of machine tool consumption to other regions of the world.

The machine tools market is characterized by a moderate growth after years of recession mainly in Europe. The global machine tool consumption, according to the ”2015 World machine tool output and consumption survey” by Gardner Research, consists in about $75 billion worldwide. With respect to 2014, the sector suffered a 0.4% contraction, but indicators in 2016 show a slow recovery. The recovery in the market of machine tools is estimated of about +5% per year for the European market, while Asia should increasingly represent the main market for these products in the future. In this global context, advanced technologies can offer a competitive edge, plus customer requirements are changing quickly and even they differ from region to region or location to location (e.g. environmental and degradation differences).

The robotics market has been growing significantly in the last decade globally. The top five markets for industrial robots are Japan, China, U.S.A., Korea and Germany. In terms of installed base, Japan leads with value of 25.1% of the entire installed base (310.508 units), after which comes North America with 16% and Germany with 13.1%. In terms of robot density, the largest average robot density in the world is in the Republic of Korea with 396 units per 10.000 employees. Japan comes second with 332 units and Germany third with 273 units. China, on the other hand, has just 11 units per 10.000 employees, meaning that there is much potential for robot installations in that market and also in other emerging countries. SMEs as system integrators face significant competition from companies operating locally and large robot manufacturers / importers. Growth and globalization can make them more competitive. Customization and technological innovation can drive growth. Nonetheless, there is also an interest in providing customer oriented solutions with a service orientation, such as system operation, monitoring, upgrading, and maintenance.

In the context of the aforementioned markets, the needs detected for the development of the novel Product-Service Systems are the following:

- *Business Model innovation:* a framework for designing the new Service-Oriented Business Models.
- *Product design techniques (Design-for-X):* techniques to be adopted in the development of the new Business Models, such as design for maintainability, design for lifecycle or design for reuse, among others.
- *Service Engineering processes:* practices for supporting services on the company’s new Service-Oriented Business Models in terms of organisational, management, processes, responsibilities, budget, etc.
- *Condition Monitoring and Fleet Management platforms:* technologies for enabling assets monitoring and servicing fleet operation and maintenance.

(2) IMPACT

Given these needs, the main impact of the T-REX project can be stated as follows:

1. **Service Oriented Business Modelling (SOBM) methodology and platform**: Methodology and tools to support companies at developing a new Service-Oriented Business Model (SOBM) by using sequential steps, guidelines and practical tools for both service and product (re-)design.
2. **Cloud-based software platform for assets prognosis and Fleet Management**: A global e-maintenance solution (KASEM® platform) for usage monitoring, failure anticipation and expertise / know-how

capitalization (remote gathering of information from embedded devices), also from the fleet-wide dimension by trends evolution, indicators comparisons and good practices sharing.

3. **Platform for a fast and easy to deploy Predictive Maintenance (PdM) solution**: Platform that allows identifying the best maintenance strategy to be applied according to customers' objectives and constrains, and fast deployment of PdM techniques.
4. **Smart datalogger for Condition Monitoring**: Embedded datalogger (ULMA Fleet Manger for forklift trucks) to capture and monitor signals for several sensors with processing capacity (and algorithms) to monitor health status, and for the remote communication of the relevant information (via 3G, WIFI or Bluetooth).
5. **Smart Pulse system for battery monitoring and regeneration**: Embedded device (ESENERGIA Pulse) for battery desulfation by means of a new Pulse technology which can also monitor several battery parameters (voltage, current, temperature, electrolyte content, charge/discharge cycles, etc.) and communicate these information (via USB, 3G or Bluetooth).
6. **Smart forklift trucks**: An overall solution offered to forklift trucks customers, including two embedded dataloggers, for the forklift truck and for its battery status monitor (also with battery regeneration by Pulses), and a software remote platform where these information at fleet level is exploited by the dealer (integrated with the ERP) and displayed to the customers.
7. **Smart machine-tool electro-spindles**: Re-designed electro-spindle following a reliability and maintainability driven concept, and including sensors (temperature, accelerometer, etc.) to provide status feedback to the machine tool diagnosis SW tool on board the CNC.

Below is explained how this impact is expected to be achieved during the exploitation phase. It is expected to reap the benefits and impact of the Product-Service Systems in the target markets by means of bringing lifecycle extension, novel Business Models and enhanced products and/or services.

(3) EXPLOITATION OF RESULTS

Exploitable results from T-REX have been characterized as a set of **five global Key Exploitable Results (KERs G1 to G5)** that integrate smaller exploitable results or sub-KERS (sub-KERs numbering indicates the Work Package producing the result).

The exploitation strategy for the global KERs is summarized below.

KER G1: Service-Oriented Business Modelling (SOBM) process and toolset (UNIBS, IAO, IK4-TEKNIKER)

Exploitation strategy:

- Apply T-REX SOBM to European Manufacturers
- Enhance through industrial research

Several capital goods sectors are interested: long-lasting, complex, and high usage-costs products. Especially SMEs are addressed (both manufacturers and dealers).

<u>KER 2.1:</u> Methodology to support the development of Service-Oriented Business Models (SOBM Reference Framework) (UNIBS)

This result can be sold and delivered autonomously by UNIBS, while other partners will contribute to its promotion and the creation of business opportunities.

KER 2.2: Methodology to support the redesign of the product-solution (Design-for-X Reference Framework) (UNIBS)

Potential customers are companies operating in capital goods sectors (in particular SMEs).

KER 2.3: Methodology for the design of support services (Service Engineering Reference Framework) (IAO)

Exploitation strategy is based on Informing and contacting potential customers by using established Fraunhofer IAO marketing and sales channels. Potential customers are service departments in manufacturing companies as well as technical service providers.

KER G2: Platform and tools for an easy to deploy Predictive Maintenance (PdM) solution for Fleet-Wide Asset Health Management (IK4-TEKNIKER, PREDICT)

Exploitation strategy:

- Use ULMA implementation as example
- Apply FW-AHM platform to Industrial sector
- Further Research to extend this approach to other industry sectors

KER 3.1: Methodology and workbench for an easy to deploy/set-up Predictive Maintenance (PdM) solution for Fleet-Wide Asset Health Management (IK4-TEKNIKER)

Part of IK4-TEKNIKER Predictive Maintenance product suite (Strategic Asset Management - SAM). Oriented towards Industrial equipment e.g. hydraulic clutches, press, machine tools.

KER 3.2: Fleet-Wide Asset Health Management platform (PREDICT)

To follow PREDICT's KASEM® general exploitation strategy. Potential customers are machine tools manufacturers and machine tools significant owners in Automotive and Aeronautics, as well as Industrial and Agricultural vehicles renters, maintainers and significant owners.

KER G3: ULMA Fleet Manager (Service solution offering an integrated platform for Condition based Maintenance and Fleet Management) (ULMA, ESENERGIA, PREDICT, IK4-TEKNIKER)

Exploitation strategy:

- 500 units expected in the next 3 years. Mainly in Long-Term Rental (LTR), but also in Short-Term Rental (STR) forklift trucks and other external forklift trucks customers (manufacturers, dealers and other brand end customers)
- Mainly focused on Long-Term Rental and Short-Term Rental ULMA forklift trucks customers

KER 4.1: New STR (Short Term Rental) Business Model (ULMA)

First year test with 50 used forklift trucks in the Basque Country area and, if success, extend in the next 5 years to the main STR Spanish markets. Potential customers are all forklift trucks end users. Two types: peaks of demand in LTR users and seasonal demand users (e.g. agriculture, music events).

KER 4.2: ESENERGIA Pulse - Batteries sulfatation restrain (by pulses) and on-line monitoring embedded hardware (ESENERGIA)

Marketing together with ULMA LTR new batteries, ULMA after-sales commercial department, and Spare parts selling companies. Potential customers are forklift trucks battery users.

KER G4: Service solution of Condition based Maintenance (CbM) for new generation Machine-Tool Electro-Spindles (FIDIA, IMATECNO, PREDICT, IK4-TEKNIKER)

Exploitation strategy:

- Sale of new service solution: local SW tool running on FIDIA CNCs plus KASEM® SW platform for supporting Fleet Management and data storage plus predictive capabilities
- Big customers are machine tool end users in Aerospace and Automotive

KER 5.1: CNC SW tool for the monitoring of the electro-spindle of the machine tool (FIDIA)

To sale the CNC SW tool as an option for the main user interface in FIDIA's CNCs. Potential customers are machine tool end users Aerospace, Automotive and general purpose applications.

KER 5.2: High Performance and High Reliability new Electro-Spindle (IMATECNO)

To sale the re-designed electro-spindle to machine tool manufacturers. Sector of application is Machinery, specifically thought to High Speed Milling Sector (Aerospace and Automotive).

KER G5: Service solution of Condition based Maintenance (CbM) for Robot and Automation Systems (KINE)

Exploitation strategy:

- Direct sales to customers, or sales through partners or collaborations
- SMEs who could benefit from automation, or larger companies such as CIE forging

KER 5.1: Servitization Business Model (based on Condition Monitoring) (KINE)

Direct sale to customers, or sales through partners or collaborations. Any robot and automation system.

(4) FOLLOW-UP EXPLOITATION ACTIVITIES

Finally, various ongoing or projected activities will benefit from T-REX results, such as projects: COBOT on Industrial solutions for collaborative and flexible robotics at logistics (ULMA, IK4-TEKNIKER) and related to KER G3; TWIN-CONTROL on Twin-model based virtual manufacturing for machine tool process simulation and control (IK4-TEKNIKER, PREDICT) and related to KER G2; Trafi-project for the deployment and monitoring of maritime emissions (KINE) and related to KER G5; SB: Digital and Transfer Initiative – Success with New Services (IAO) and related to KER G1.

(5) SCIENTIFIC DISSEMINATION

Ten scientific papers have been published in the course of T-REX project. The following is a list of selected papers:

- Adrodegari F., Alghisi A., Saccani N. "Towards usage-oriented business models: an assessment of European capital goods manufacturers" In Proceeding of EurOMA (European Operations Management Association) - Palermo (IT), June 2014.
- Arnaiz A., Revilla O., Saccani N. "Extending manufacturing towards service-oriented business models: The T-REX technological levers that support this extension" IBS (International Business Servitization Conference), November 2014.
- Adrodegari F., Saccani N. "From Ownership to Service-Oriented Business Models: a survey in capital goods companies and a PSS typology", In Procedia CIRP (7th CIRP IPSS Conference), vol. 30, May 2015.
- Alghisi A., Saccani N. "A business model approach to servitization: development of a new typology" In Servitization: the theory and impact. Proceedings of the Spring Servitization Conference (SSC2015), Aston Business School, May 2015.
- Hans-Jörg Bullinger, Thomas Meiren, Rainer Nägele "Smart Services in Manufacturing Companies", In Proceedings of the 23rd International Foundation for Production Research (IFPR), August 2015.
- Adrodegari, F. Saccani, N. Kowalkowski, C. "A framework for PSS business models: formalization and application", In Procedia CIRP (8th CIRP IPSS Conference), vol. 47, pp. 519-524, 2016.
- S. Fernandez, C. Mozzati, A. Arnaiz "A Methodology for Fast Deployment of Condition Monitoring and Generic Services Platform Technological Design", In Proceedings PHM Europe, pp. 70-79, July 2016.

(6) INDUSTRIAL DISSEMINATION

Industrial dissemination has focused mainly on press releases, production of videos, exhibitions, workshops and other events.

There was prepared both printed and digital dissemination material as **two T-REX flyers** and **five posters** for different exhibitions and events.

Also **four videos** have been produced and published in YouTube by IAO, KINE, ULMA and FIDIA, the last of them also as demonstrator of Machinery use case results.

Almost **thirty press releases** devoted to developments and results from T-REX project have been produced by ULMA and UNIBS in websites and magazines.

Participation in **five exhibitions** includes the EMO machine-tool world exhibition in Milan 2015. As well as the 29th BIEMH International Machine Tool exhibition plus the 6th LUBMAT, both in 2016, where results on forklift trucks were presented, and the IT2Industry@AUTOMATICA International Trade Fair for Automation and Mechatronics and PHM Europe in 2016, where both T-REX project and KINE progress in Automation use cases were shown.

T-REX was also a topic of more than **thirty workshops** attended in the course of the project. To name a few, the Industrial Technologies 2014 Conference in Athens, a common workshop of several FoF maintenance projects like iMAIN, Power-OM, SUPREME, EASE-R3, SELSUS or TRANSPARENCY. The Innovationsverbund "Service Platform Maschine" in 2014, where there were discussions of T-REX related activities and results of

T-REX survey. The Seminar on Service Engineering in 2015, with presentation of current results of T-REX with participation of 16 German companies (manufacturing companies as well as pure service providers). Participation in the workshop “ASAP Service Management Forum: How to develop successful service strategies?” in Brescia 2015, a workshop of academic character where some the T-REX results where disseminated. REMANufacturing Gipuzkoa in 2015, a Remanufacturing issue at Spanish national level and at Gipuzkoa local area. The “Setting Up the Innovation Appetite” workshop driven by ASAP Service Management Forum & TAU-MA in 2015. Factories of the Future (FoF) IMPACT WORKSHOP in 2015 and 2016 (organised by the European Commission in cooperation with EFFRA). The event Engineering smart services along the lifecycle in 2016, organized by the EUnited Metallurgy (The European Metallurgical Equipment Association): “New Trends in Technical Services” Working Group. EUnited Metallurgy is the voice of the European industry suppliers of metallurgical plants, components and electrical equipment, automation solutions and services. A special session promoted by T-REX at 8th CIRP IPSS CONFERENCE, Product-Service Systems across Lifecycle, 2016. And a workshop on “Industry 4.0: Optimisation of machinery lifecycle, component re-use and Servitization”, organized by T-REX Consortium at project finalization in order to take advantage of final review meeting to disseminate globally T-REX results and open potential collaborations with external companies.

Among other events, it is worth citing the **FIDIA Open House** 2015, with customers visiting FIDIA facilities, and the Forum “Smart Services” where some results of the T-REX project were presented in a keynote speech.

And overall, between 2014 and 2016 **more than twenty presentations in conferences and seminars** were done contributing to disseminate T-REX progress and results.

(7) OTHER DISSEMINATION ACTIONS

The dissemination through **T-REX website** has been massive, with more than **sixty news articles** published, and also with the publication of the **five project newsletters**, that have been followed thanks to a RSS feed.

Other actions include the publication of **nine informative articles** in local bulletins and journals by the academic and technological partners, and **one article** at the European Commission DG Research website within RTD Success Stories.

(8) FUTURE ACTIVITIES

After project finalization (October 2016) the 3rd IFAC AMEST Workshop was attended, and a new scientific contribution published (“Advanced Maintenance as Enabler for Service Oriented Business Models (BM) – an Application in Forklift Trucks”, in the Proceedings of IFAC AMEST, 2016).

4.1.5. Project contact

More information is available in T-REX Website: http://t-rex-fp7.eu/

Or can be requested by writing to the Project Coordinator Aitor Arnaiz: aitor.arnaiz@tekniker.es

The list of participants and their websites links are available also through the T-REX project website: http://t-rex-fp7.eu/index.php/partners

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