Advanced maintenance as enabler for service oriented business models (BM) – An application in forklift trucks

Aitor Arnaiz*, Jean B. Léger, Asier Aguirregomezkorta*****
Santiago Fernandez*, Oscar Revilla*, Flavien Peysson**

**Fundación IK4-Tekniker, Eibar 20600, Spain*
(Tel: 34 943 206744; e-mail: aitor.arnaiz@tekniker.es).
***Predict, Vandoeuvre Les Nancy 54500, France*
(e-mail: jean-baptiste.leger@predict.fr)
**** ULMA Forklift Trucks, Oñati 20560, Spain*
(e-mail: asagirre@manutencion.ulma.es)}

Abstract: The current phase of global economy competitiveness under economic downturn are pushing many sectors related to manufacturing industry to adapt and discover new ways to make profitable businesses. In particular, there is a trend for manufacturers towards service oriented business models: That is selling the usage or even the product performance.

However, these new business completely change the manufacturer's perspective over the costs and revenues arising during the product lifecycle, and therefore the relevance of concepts such as life cycle costs or maintenance management strongly increases. Thus, the reduction of costs related to the product usage and maintenance is mandatory in order to achieve a profitable business.

This paper presents an example of this transition to service oriented business models. In particular, it presents the business opportunities of an SME that produces forklift truck solutions. The paper will focus on how maintenance technologies are enabling the generation of new service oriented business and how these new technologies do influence in the main KPIs of the company.

Keywords: Condition Monitoring, Sensors, Signal Analysis, Failure Analysis; Maintenance Models and Engineering; Asset and maintenance management, Product-Service, KPIs.

1. INTRODUCTION

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 (Takata, 2013). 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 (e.g. pay-x-performance). All these emerging trends fall within the equivalent concepts of 'Product-Service Systems' (Tucker, 2004) and 'servitization' of manufacturing (Vandermerwe and Rada, 1988).

These new business 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, life cycle extension or maintenance management strongly increases (Takata et al, 2004), 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 new business models (BMs), especially on manufacturing SMEs. 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 (Adrodegari et al, 2015).

This paper presents an example of a successful transition to service oriented business, related to a forklift truck integrator SME. This example is developed within an R&D project where different methodologies and technologies have been developed in order to leverage and support the creation of new BMs, in particular advanced maintenance technologies. Therefore, next chapter will show the use case, as well as the R&D background. Next, the specifics of the maintenance methodology will be shown, and this will conclude with the evaluation of the feasibility of the new service oriented model in terms of main KPIs.

2. THE USE CASE IN TRANSPORTATION

2.1 T-REX project – The transition to new service oriented BMs. Technology enablers

The European project T-REX[1] is targeting the development of specific technologies and tools (grouped into four different 'levers') that will empower the companies (specially SMEs) in the development of advanced service-oriented BMs for new Product-Service Systems (PSS) offering, thus promoting a shift from value in exchange to value in use for customer needs satisfaction.

New BMs that do not transfer the product ownership offer extended opportunities, with respect to traditional BMs, regarding the redesign of the products, the after-sales services and supply chain, and the manufacturer-customer relationship (see Table 1).

This project has started in October 2013[2] to support companies satisfying current customer needs, enhancing the company's performance, enabling to diversify its business and achieving a competitive advantage. In particular, defining and implementing a new Product-Service Systems (PSS) offering is a demanding process, and T-REX understands that several methodological 'levers' should be deployed: Among these, we highlight two:

1- A framework and methodology to understand how to derive a new service oriented business from current activities;

2- A methodology for fast deployment of integrated local monitoring and fleet management, customizable to the industry requirement;

Firstly, the framework guides the identification of new BMs through a PSS typology organised in 5 different types of ownership-oriented and service-oriented configurations, as explained in (Adrodegari et al, 2015) and shown in Figure 1. Each type takes care of the needs in advanced maintenance technologies as potential enablers of the new model.

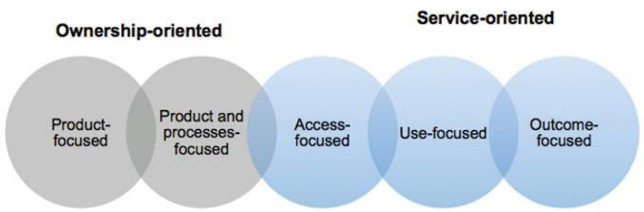

Fig. 1. PSS types (Adrodegari et al, 2015).

[1]T-REX: Lifecycle extension through product redesign and repair, renovation, reuse, recycle strategies for usage & reusage-oriented BMs).

[2] www.t-rex-fp7.eu

Table 1. Traditional vs. new BMs – main differences

	"traditional" BMs	"new" BMs
Product design	Product is designed for the minimum cost Lifetime should be enough	Product cost is less important. The relevant cost is the Total Cost of Ownership. The product is configured for the application. Product lifetime is enlarged.
Services, supply chain and customer relations	Product developer establishes conservative PM policies. Maintenance is made in house or by third parties After-sales services, mainly technical assistance and spare parts, are sources of revenue for the manufacturer (or third parties)	Product developer makes extra effort to minimize maintenance cost: leveraging on techniques and tools to optimise preventive and emphasize on prediction Services allow the increase of product availability
Customer relations and Cash flows	Product sales as a one-off transaction In the usage and end-of-life phase interactions between the manufacturer and the customer may not occur. If they occur their monetary value is often negligible compared with the product value Product developer is not aware of the conditions in which the product is in operation Dismantling is in charge of the user	Product-Service Systems provision as a relational, long-term process Stable and continuous cash flows from customer to manufacturer over the product lifecycle, of a smaller entity compared to product sales Cash flows cover both the product and service component of the offer Product developer is aware of operating conditions Information from the product is collected to increase product availability (e.g. Condition Monitoring), to increase service efficiency (e.g. remote control/ diagnosis) and to transform field feedback into input for designing new products and services End of life is in charge of the producer. Some modules could be re-used

Secondly, the methodology for fast deployment of a condition monitoring system retrieves the resulting business model as a main driver to construct a cost-effective solution.

The project is supporting such business transition by developing and experimenting the 'levers' within three practical case studies in the transportation (forklift trucks), machinery (machine tools) and automation (robot solutions) domains. This paper focuses on the transportation domain.

2.2 ULMA Forklift Trucks

ULMA Forklift Trucks has more than 30 years of experience in the development of integral logistics solutions, tailored to any many different types of clients and sectors, where manufacturing areas have an important weight.

ULMA Forklift Trucks is a leading company within the manufacturing sector related with the shifting towards more service oriented related business. In particular, business has shifted dramatically from product sales to rental services since 2007 until now. Now the company has more than 2000 forklift trucks on rental, mostly long-term, and has a solid business based on novel ways of financing and technical assistance.

However, in the strategy to increase the market share, ULMA joined T-REX with the purpose of analysing the potential of extending the actual business towards more market niches and business types. Because of the analysis of the market potential several new BMs arise: One of them is the development of an offering where the cost is calculated in terms of usage instead of in terms of time. Another very promising business is the short-term rental of the trucks, taking advantage of the fleet mobility. A last business opportunity is related to the refurbishing of second hand trucks, in particular targeted at heavy duties (e.g. foundry, forging,…).

Fig. 2. ULMA Forklift trucks include a great variety of products and services.

In all three cases it is mandatory to include an advanced maintenance scenario, with a monitoring system where usage and condition information can allow the estimation of the useful life consumption of the components and linked to the contracts, and appropriate fleet management can derive indicators of the real cost-benefit of each approach.

3. THE TECHNOLOGY: ON-LINE LOCAL MONITORING AND FLEET MANAGEMENT FOR ADVANCED MAINTENANCE

3.1 A methodology for the deployment of adequate local monitoring

The technologies that support the development of advanced maintenance scenarios, enabling the change from traditional "fail and fix" practices to "predict and prevent" strategies (Lee et al, 2006) have gained much importance during the last decade as a result of the advance of acquisition, and communication technologies and the increasing operation performance requirements.

Challenges remain however in structuring the condition monitoring offer due, in particular, to the variety of potential domains of application, the characteristics of the existing information and the final goals of the monitoring activities. These challenges may influence in the deployment time of a condition monitoring solutions, which can convert a potential solution into an unfeasible approach due to extended costs and deployment delays.

T-REX has developed a specific methodology condition monitoring deployment from the starting point of a new BMs, with special interest when there is zero or minimum knowledge about the potential of the monitoring solution, as it happens in manufacturing and integration SMEs. The methodology tool aims to capture a high level perspective and to focus on key information at the right level of detail, facilitating faster iterations between maintenance technologist and PSS owner until a complete understanding of the maintenance requests and features – and their cost. Existing support tools are applied when deemed necessary (e.g. criticality matrix, FMEA, etc.).

The steps defined within the methodology tool are: *business perspective, technical objective, technical analysis and data monitoring*. Within each step, focus and value are stated.

The first step on *business perspective* states the focus and the impact expected from the technologies in terms of the value introduced with respect to the (business) goals. The perspective or focus of the value improvement are linked to financial or maintenance perspectives, but other aspects might be relevant as well (e.g. customer, product, service, learning, marketing…). In turn, the value expected from the technology is stated in clear terms of maintenance, lifecycle, unavailability and risk, among others.

As regards the step on *technical objectives*, the overall objective of the technology is stated in relation to the business perspective. Various technological approaches may jointly contribute to achieving the same target (business) value. One of the main values is the reduction of the different motivations to very few and clear 'technical drivers', in particular condition monitoring, remote diagnosis, prognosis, usage and performance monitoring. The technical focus is also stated, indicating the technical rationale and approach to be pursued.

Business		Technical	
Perspective	**Value**	**Objective**	**Focus**
Financial / Reusability	**Re-use:** enables re-usability of components/systems or extending lifecycle, increasing income / decreasing annual expenses. **Income:** may increase with actual usage known. Decreases other (financial) risk. **Maintenance:** enables improved preventive maintenance intervals and improves reliability, thus reducing maintenance risk and potentially costs.	Usage	Operational time
Financial / Reusability		Usage	Operational time
Financial / Reusability		Usage	Component usage time
Financial / Reusability		Usage	Component usage time
Financial / Maintenance	**Maintenance:** Decreases maintenance cost and risk, as failures can be detected/anticipated/avoided and remote diagnosis performed; or allow product life-cycle extension with higher or lower maintenance costs.	Usage	Impact occurrence

Fig. 3. An excerpt of the result of the first two steps of the methodology.

The next step, *technical analysis*, states the critical functional aspects and the means to pinpoint them. Once stablished the drivers (e.g. remote diagnosis), this phase leads to the development and implementation of the monitoring algorithms that will be applied. As its main focus, functional failures and functional critical aspects to be tackled are stated. In general, any condition needing attention. As final value of this step, potential indicators are formulated, describing the data used and their attributed examined. It is a higher level of data description than monitored data/signals, from which indicators stem. Some examples are statistics, characteristic frequencies, etc. from which, for instance, health condition can be directly determined in some cases, or derived in some others. Figure 3 includes an excerpt with some of the variables taken into account in the business perspective and technical objectives.

The final step within the tool is *data monitoring*. In this step, the parameters and processing leading to the extraction of relevant indicators are stated. This is the closest stage to hardware level and some interaction is expected in order to clarify and refine options. First, parameters (the raw data or signals to be monitored) are shown. Typical examples are physical sensors (temperature, accelerometer, current, and so on) but other possible sources of data can be included (for instance counters). Then the appropriate formulas are stated, this is to say, the processing needed to derive useful indicators for the analysis. Examples are calculations related to signal processing and simple condition algorithms. A Personal Computer (PC) based simulation environment mimics the expected operation of the local monitoring hardware according to the first sensor data available. This serves to correct and fine-tune the behavior of the local condition

The methodological approach also carries an evaluation of the best hardware options to implement the algorithms. Depending on the business perspective (including cost-benefit analysis) and of the technical objectives (frequency, signal quality …) the hardware choice to implement the algorithms can be quite different:

- In many cases today machinery embeds advanced processing boards such as in the machine-tool use case, where CNCs embed many PC functionalities. In these cases the most convenient is to incorporate the new CM functionalities directly to the existing control, in many cases using specific interoperability solutions.

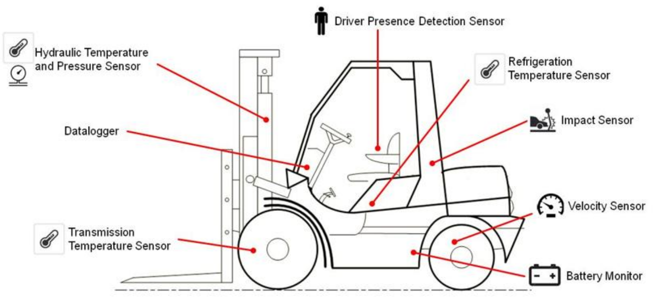

Fig. 4. Graph showing the final data monitoring for fork lift-trucks.

- In some cases, low requirements in terms of robustness and/or doubts with respect to the final solutions could lead to initial prototypes or small product series based on existing/standard communication and data acquisition platforms (e.g. Raspberry-BI, Arduino, National Instruments DAQ).

- Finally, in some cases, such as in the case of this forklift solution, when requirements are clear and unitary costs are of special importance, best solution is to develop a custom-made electronics. Figure 5 below shows the HW developed during the project.

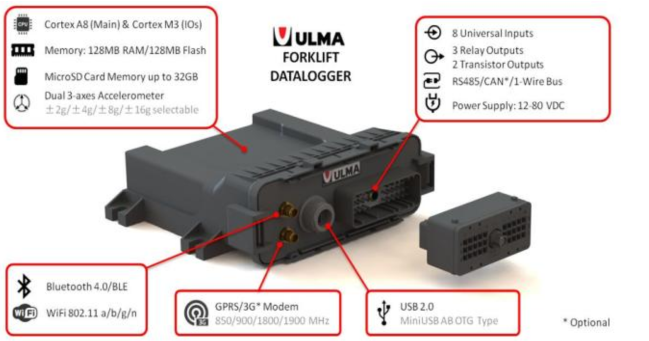

Fig. 5. Embedded data logger developed for transportation after an analysis of the existing HW solutions.

3.3 A software platform to support fleet operation

In recent years there have been significant advances in both embedded and cloud systems, increasing the power and capabilities of the former, expanding the scope and increasing the services provided by the later.

The platform deployed in T-REX incorporates a remote fleet management SW (KASEM[3]) as a necessary complement to the local condition. The local, embedded system specializes in monitoring and communication capabilities, which

[3] https://www.predict.fr/en/products/kasem/

achieves certain data processing such as event detection and local alarms. The remote system, on the cloud, specializes in global management and services, mainly rooted in their data organization, processing and analysis capabilities from data gathered by, typically many, local systems. A communication link between local and remote systems must be established for them to act in a coordinated manner.

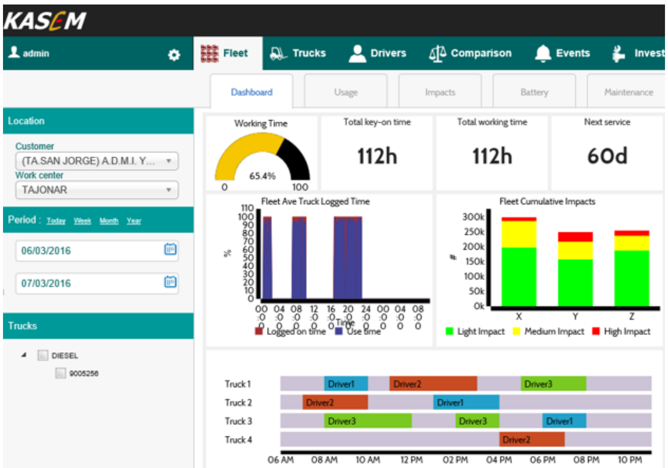

Fig. 6. Several indicators for truck fleet management SW (Screen excerpt)

The functionality available locally and remotely vary depending on the business perspective of use case and, therefore, depending on the final technical objectives. For instance, final local transportation monitoring system, embedded in a low-cost specific electronics, will carry out less functionality than a local monitoring system for a machine tool, deployed into a PC-like computer numerical control (CNC).

Overall, there are a series of functions, mainly related to 'fleet' related storage and machine learning processing that should be developed at a remote platform. Both local and remote modules may share part of the indicators derived from the data, but the later will benefit from a broader vision to offer to the customer, as well as the possibility of revising and enhancing the indicators through business intelligence and machine learning processes. These, in turn, may derive new indicators or parameter settings, which should be taken into account locally.

4. THE IMPACT: THE POTENTIAL OF ADVANCED MAINTENANCE ON NEW BUSSINESS MODELS

A clear evaluation of the potential benefit of each new BM has been the key driver along this work, stemming from the cost-benefit analysis of maintenance strategies, as reported in Gilabert et al. (2015). In this sense, four main KPIs were highlighted since the beginning as the most important ones to follow: lifecycle extension, re-use increase, maintenance cost reduction and overall lifecycle cost reduction. The evaluation is made *a-priori* using the existing information (from currently ongoing BMs)

Concerning forklift trucks, advanced maintenance is one of the main levers enabling improved BMs related to short-term rental service, a type of service increasingly demanded by customers that is being the basis for the impact evaluation.

In particular, the qualitative impact of the adoption of advanced maintenance is summarized as follows:

- Concerning *Short Term Rental services* (STR), the development of the advanced maintenance scenario allows the monitoring of maintenance and operation of the whole fleet, which is a key enabler for the fleet mobility and flexibility demanded in STR at reasonable costs (with scenarios of minimum usage of one day).
- Concerning Long Term Rental business, a new iteration of the BM is foreseen, when advanced maintenance technologies are complemented with re-usage of specific components. The result is a *second hand LTR services* business (contracts spanning from three to five years) specially aimed at heavy-duty operation scenarios. In this case there is a combination of technologies, which enables this new business: the recovery and refurbishment of first hand components, including battery pulse regeneration; and the advanced maintenance, with particular attention to condition monitoring of second hand parts and batteries.

In addition to this, T-REX has also developed a quantitative assessment and evaluation tool to perform coherent quantitative assessment of the benefits achieved by each new business, in terms of KPIs, with respect to traditional business. This tool incorporates also the economic benefits that new technologies (e.g. advanced maintenance, battery regeneration) may bring to the new BMs. The quantitative details are mainly decomposed into costs (investment, annual maintenance, annual others), revenues (initial, annual, residual value) and risks (maintenance, operation, others).

At the end, the calculated KPIs states that the LTR BM is profitable, in the sense that there is an estimation of a reduced Life Cycle Costs (LCC) with respect to the existing BM. In this case, LCC reduction ranges from 9 to 18%, with a specific Life extension from 60 to 100% and a substantial increase on component re-use (between 50 and 80%). It is also worthy to notice that maintenance technologies, together with battery pulse regeneration technologies that can sustain longer battery operating life, are key to decrease risks that otherwise impact very aggressively on the previous KPI estimations. In this sense, maintenance costs could increase and LCC benefit could decrease dramatically or even disappear, with actual risk analysis estimation, if no advanced maintenance is applied.

5. DISCUSSION AND FURTHER WORK

Previous section has stated that the inclusion of advanced maintenance technologies (in particular a combined system with local data logging of key data and a remote system that enables fleet wide monitoring) is an enabler for the development of rental short term services (STR) as well as for the development of second hand Long Term Rental business. This statement relies on two premises: First, the estimation of future costs, revenues and risks related to the new BMs developed relies on the business knowledge of the sector and the capabilities (and boundaries) of the advanced maintenance system. Second, an advanced maintenance system is already in operation at ULMA. This will serve to validate and adjust the actual BM evaluation.

As project is not yet finished (the project will end in September 2016), the validation of the business BMs is still ongoing and will still have an extensive revision in coming months. In any case, ULMA considers that the results obtained, together with additional analysis (e.g. financial evaluation) are valid enough as a starting point for the business development and is progressively implementing these options within its business offer.

On the other hand, the paper has made a quick overview of the different technologies that support the new business model development. First, the step-wise methodology of stating the best local condition monitoring module from the business opportunities detected. Second, the fleet wide heath assessment solution provides a fast deployment of any solution as well as connectivity to any local module. Last, the tool for BM assessment provides a coherent quantitative framework that can be used internally at companies to understand and detail cost-benefit items that impact at operation and maintenance. The potential flexibility of these tools to scale and translate to other domains is currently being tested as the application to other use cases continues.

Finally, it is interesting to remark that these new businesses options led to stable revenues coming from a wider after-sales services portfolio related to the equipment's operation and maintenance. In addition, such models entail environmental benefits too through increased duration, renovation and reuse of product modules. At the very end, these new business stems from the translation of already known environmental concerns regarding the wastes (energy, raw materials,…) into real influence into the life cycle costs, as resources, energy and wastes are translated into economical terms, as suggested in the image below, a revised comet cycle from (Takata el al, 2004)

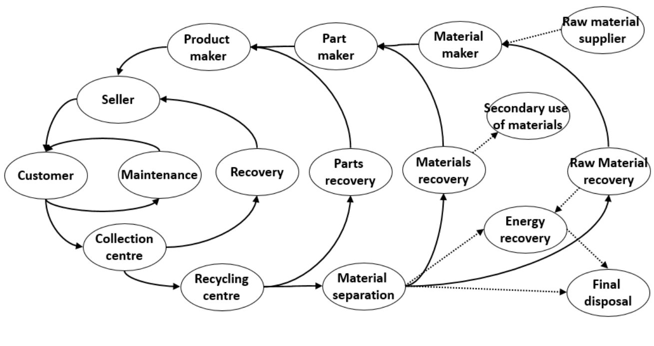

Fig. 7. Graphical simplification of Ricoh Comet circle TM[4]. The graph shows the increased steps (and often cost) associated to a scenario of zero-waste and re-manufacturing concepts. The more to the right in the activity cycles, the higher cost these activities represent with respect to operation. In order to enhance customer satisfaction it is necessary to extend at maximum the left inner circle activities. That is, it is necessary to extent at maximum the maintenance, reuse and remanufacturing activities.

[4] Comet circle is TM of Ricoh, Co., Ltd.

ACKNOWLEDGEMENTS

This paper has been written under the framework of T-REX project, which has received founding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 609005

REFERENCES

Adrodegari, F., Alghisi, A., Ardolino, M., & Saccani, N. (2015). From ownership to service-oriented business models: a survey in capital goods companies and a PSS typology. Procedia CIRP, 30, 245-250.

Gilabert, E., Fernandez, S., Arnaiz, A., & Konde, E. (2015). Simulation of predictive maintenance strategies for cost-effectiveness analysis. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture.*

Lee, J., Ni, J., Djurdjanovic, D., Qiu, H., & Liao, H. (2006). Intelligent prognostics tools and e-maintenance. Computers in industry, 57(6), 476-489.

Takata S., Kimura F., van Houten F.J.A.M., Westkamper E., Shpitalni M., Ceglarek D. and Lee J. (2004). Maintenance: Changing Role in Life Cycle Management". Annals of CIRP, 53/2 (2004/8), 643-655

Takata, S. (2013). Maintenance-centered Circular Manufacturing. Procedia CIRP, 11, 23-31.

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business strategy and the environment, 13(4), 246-260.

Vandermerwe, S. and Rada, J. (1988). Servitization of Business: Adding Value by Adding Services. European Management Journal, 6, 314-324