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DPLE – Digital product lifecycle engineering for hydrodynamic bearings

Engine Component Developments - Tribology

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ABSTRACT

As competition levels increase continuously in invest markets for energy and transportation every component must be optimized to the essential requirements to be successful. This applies to the hydrodynamic bearings as well which must be customized, balancing function, reliability and cost to the specific optimum. Opportunities from digitalization are increasingly employed to realize the optimum product for an application more precise and faster. DPLE - Digital Product Lifeycycle Engineering is the comprehensive tool chain interacting and interfacing to drive this. The paper will explain the current status of DPLE implementation, development and expectations for the future. The paper will focus on the following elements of DPLE.

Customized Bearing Solution
Consequently DPLE results in customized products to the individual application. While this has been the aspiration and need within the industry for quite some time the additions of the digital revolution allows major steps to get there.

Continuous Data Flow following the maturity level of the product in development including a feed-back loop
Generating, storing and sharing product data over the full product lifecycle starting with the requirements and closing with the end-of-life analysis is the prerequisite for the method of DPLE. A feed-back loop is continuously reaching from end to start.

SOR – Specification of Requirements
The SOR is set-up in a standardized digital format and environment to set and ensure format, content and interdependencies. It is the very important interface and joint platform for the engine and bearing engineering experts.

Product Design and Engineering
From layout until final product design engineering is developing based on one consistent and evolving data set. The engineering toolchain is pulling from and feeding into the one data stream assuring the permanent validity of inputs and outputs.

Single Product Data documentation
Production data management over the complete value chain enables tracing of process and product characteristics at any step. Artificial intelligent methods allow complex model generation which may lead to engineering and production measures in consideration of functional consequences.

Application Data Monitoring in testing and real world
Smart bearings with plug and play features offer new insides of application conditions and needs. These insides support the validation of engineering and product design. This is especially a great chance to increase the quality, speed and capability of simulation.

End-Of-Life Data evaluation
Intended bearing operation and failure modes can be investigated in test-bench operation to a large extent. Accelerated durability testing is an even higher challenge. Real world application durability data from end-of-life evaluation therefore is a very effective addition for calibrating the test and simulation profiles.

Data Security and Accessibility
Data security and accessibility are non-comprisable must haves to protect all contributions and contributors and assure the effectiveness of the engineering environment.

1 INTRODUCTION

As a supplier for high loaded bearings for the combustion engine industry the major task is not only providing a bearing product but to accompany the component over the whole application life cycle.

To be and stay a valued partner of the applicating industry besides a reduction of time to market and adequate product costs, lean and efficient processes along the whole value chain are necessary.

On the work force side avoidance of overload with permanent repeated routine tasks (MUDA) is needed. Instead using people's expertise accompanied by statistics (data mining of product and process values) for 1st time right and product and process optimization using digitization is the state-of-the-art opportunity. Besides the direct efficiency gains employee's engagement will raise resulting in substantial engineering performance increase.

DPLE - Digital Product Life Cycle Engineering is the comprehensive interacting and interfacing tool chain to drive this. The paper will explain the current status of DPLE implementation, development and expectations for the future.

The key elements of DPLE are:

- Application layout configurator and data base
- Bearing test rig references
- Digitalization of production process and quality data management
- Bearing judgement and application data monitoring
- Data mining and interpretation

A further section will deal with the prerequisites as:

- Software Interfaces
- Data access and security
- System performance
- Legal aspects

2 THE CONCEPT OF DPLE

Already now many digital systems are in use dealing with the different aspects of product layout product design, production quality and validation. Additionally, a significant amount of data and knowledge is stored unstructured "somewhere" on network drives or local drives only.

It is obvious that such a situation is suboptimal for know-how build-up, knowledge distribution and an efficient application optimized product development.

The Product development process (PDP) as a formal procedure is handled via the so called IMS (integrated management system) available via the Miba "intranet". The formal process steps to be fulfilled are well defined but especially the technical results and data are neither visible within the IMS nor has it been considered to cover technical details.

To improve the situation, an overall approach in cooperating working processes and dealing with the interfaces of several software solutions has to be taken. As shown in Figure 1 a holistic closed cycle approach along the product development is key. Although all of the phases are in place already now, a structured data storage and interfaces are missing to exploit the full potential of data mining with minimum resources.

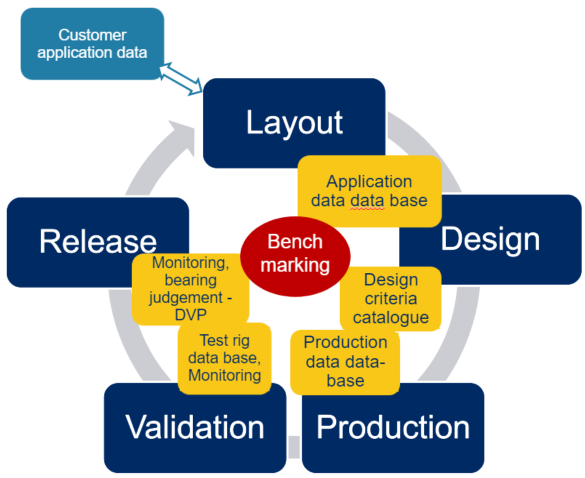

Figure 1. The generic concept of DPLE

Therefore, Miba is working on several aspects, processes and interfaces to improve this situation. In the following major elements towards this goal are described, sharing insights, showing already successful running systems and also pointing out challenges.

3 BUILDING BLOCKS

3.1 Application layout solutions

Miba's Bearing Division is developing and constantly improving so called Configurators. A Configurator is a customized software solution that connects the customer and the application engineering departments during initial phases of the layout and design process.

These valuable tools for both the engine business as well as the heavily evolving wind business have a strong impact on time to market reduction.

The solutions support the standardization and help the internationally acting teams to follow similar routines, share the same data set worldwide and produce aligned reports (e.g., for feasibility).

The digitalization of these first steps of the solution process for a highly engineered product reduces the response time but it is a long and intense process to bring working routines, gut feelings, excel lists into a simplified and user-friendly front-end.

The steps that have been proven successful in the Bearing Division as well as the main features will be described under the following bullet points:

3.1.1 Customer Journey Mapping (CJM) as basis for software solution need

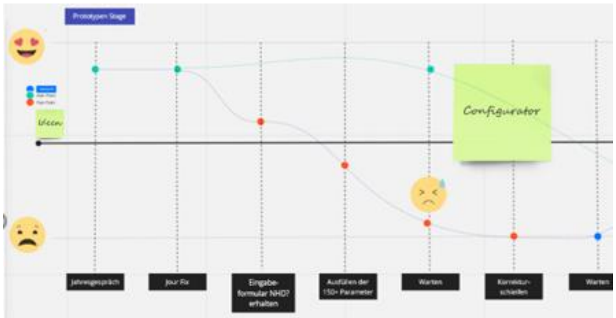

Figure 2. Example for Customer Journey Mapping at Miba

The fundamental idea behind CJM [1] is relatively simple; it is a visual depiction of the sequence of events through which customers may interact with an organization during an entire engineering process. It represents a graphical schematic of all the possible organizational touchpoints that customers may encounter during an entire development process.

In Miba the mapping showed a need for digital touchpoints with the customers to increase speed and quality of data alignment.

3.1.2 Development of UI /UX Prototypes

To fill those digital touchpoints mentioned under 3.1.1. with usable software features it has become very common to work with so called UI/UX Prototypes. Their development increases the speed during the actual software development and it helps to bring future users on board and into the discussion.

This kind of prototype is a simple clickable online screen that is easy to adjust and to access. The visualization is key when discussing the look and feel with the users and developers.

3.1.3 Software development in scrum framework

The software development of the Bearing configurators is performed by Miba IT and Digitalization Department. The entire department is working with these methods.

Scrum [2] is a lightweight framework that helps people, teams and organizations generate value through adaptive solutions for complex problems.

Following this framework during the development of the Bearing Configurators supports an iterative and flexible but value driven approach that integrates the users from the start.

3.1.4 Main Features of the Engine Configurators

Customers are invited to use the online Configurator, to fill in the relevant technical data structured in several steps.

During these steps the customer is required to provide information regarding all layout relevant data as Crank Train geometry, mass and material data, Cylinder Bank definition and details in regard to Crank Pin as well as Main Bearing Pin surface quality. In addition, operation specific data as engine speed and load tables will be provided.

Guiding the external user through these features and making sure the workload stays self explanatory was the main aim during development. Possibilities to copy and auto fill data are given; drawings can be uploaded; many aspects have been translated into simple graphs that avoid confusion and the usual back and forth for clarification.

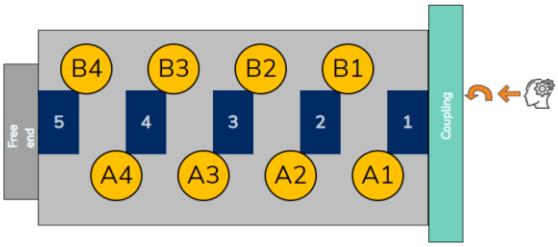

Figure 3. Visualization of Crank Train and Cylinder Bank; Coupling Side

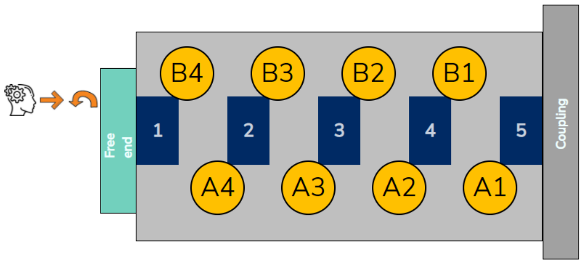

Figure 4. Visualization of Crank Train and Cylinder Bank; Coupling Side

One example is shown under Figure 3 and 4. To define the view onto the Crank Train and Cylinder Bank the graphic clarifies the rotation direction as well as the view direction.

For immediate feedback and verification of the data input a bearing force plot is generated based on the engine specification in combination with a selected firing pressure curve and rotational speed. An Example of a MB #2 force plot of a V8 engine is depicted in Figure 5.

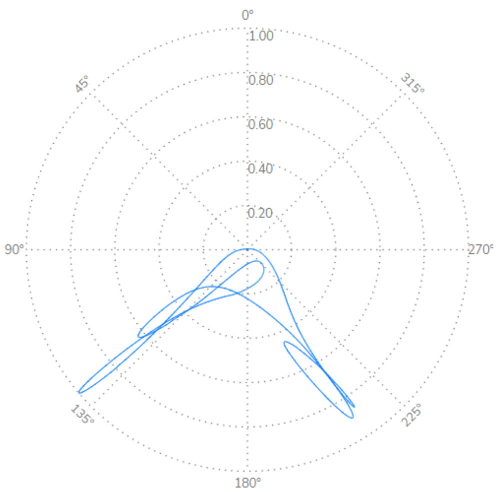

Figure 5: “Rigid” Force plot as instant data input verification

After completion of the data by input of the engine configuration parameters the user can inform the respective Miba Application Engineer who will then create an automated feasibility report including all data and graphs.

3.2 Digitalization of production process and quality data management

A few years ago, the need for a change to a digital transformation initiative was born. It was obvious that digitalization is a key success factor which can be seen as a differentiator. All our processes have been analysed with the support of leading experts. This stress test took more than half a year and the outcome was a powerful gap analysis with very good roadmap indications. For sure these analyses were just an indication how the organization could develop and what recommendation could bring which benefit. Overall, it was clear to establish an internal organizational initiative together with the IT department to be sustainable and successful on the long run. With this drive from the customer needs and IT support an out of the box thinking was established. Overall, a lot of good ideas were born, and pillars have been set for a sustainable digital footprint.

3.2.1 Planning

In a highly dynamic production environment, an effective and flexible material flow is necessary to improve business productivity and process efficiency. By dealing with all this complexity at sales and operations planning, production planning, and procurement planning the right balance will help to secure a healthy Economic Value Added (EVA), as shown in Figure 6. Miba’s vision is to bring all these interactions together and find - with suitable algorithms - the right demand planning and production program.

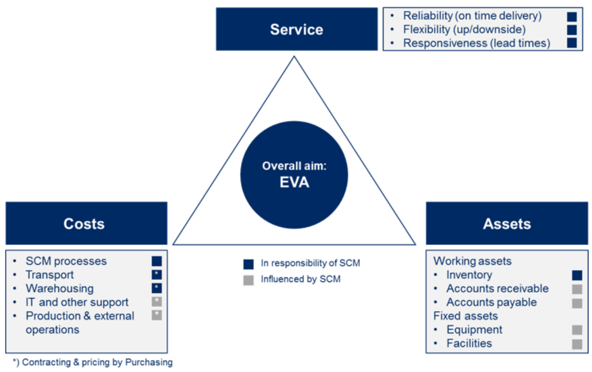

Figure 6: EVA Triangle of Interactions

3.2.2 Smart Factory

Smart factory, frequently referred as Industry 4.0, uses the integration of advanced technologies, such as IoT, robotics, and AI, in manufacturing to create a more connected, automated, and data-driven manufacturing process. In our understanding we want to use these digital technologies to increase efficiency, reduce costs, improve quality, and increase flexibility in manufacturing.

Miba´s approach of a smart factory should be to create a self-monitoring and self-optimizing system that can make decisions and take actions with less human intervention.

A very important component on the so-called digital landscape is the examination with the digital twin approach. A digital twin is a virtual representation of an object, system or task. This digital model should represent the real-world with its characteristics inclusive data and assets. Our main expectation is to combine all these layers and do simulations to increase efficiency at our time to market process with balanced production costs.

3.2.3 MES (Machine Executive System)

Key functionalities like production scheduling, data collection, quality management and performance analysis have to interact in relation with machine data in order to automate certain process task and being a functional layer between the ERP (Enterprise Resource Planning) system.

The understanding is to bring transparence and visibility to all departments by increasing the uptime, reduction of inventory, improved quality controls and a paperless shop floor.

There are a lot of positive examples and changes which bring value to the shop floor. The utilization of the production assets by improving the overall equipment effectiveness (OEE) is one major achievement. Moreover, nearly no printers are necessary anymore at the shopfloor. All relevant documents can be displayed at the production terminals. All necessary records are immediately available to decision takers across all integrated systems.

3.2.4 IIoT (Industrial Internet of Things)

IIoT is an application of IoT (Internet of Things) in industrial settings, which enables the connectivity of machines, equipment, and other industrial assets with the internet, allowing them to communicate with each other and with people.

In our interpretation it allows real-time data collection, analysis and visualization, which leads to improved decision-making, predictive maintenance and optimization of production processes.

One of the most difficult questions at this stage was the development of the right IIoT architecture. There were a lot of question marks at the connection, database, interface, device etc. Moreover, the huge variety of machines, sensors with their applications must be considered.

Finally, with a lot of exchange with other industrial leaders and experts we found out that we have to establish our own architecture with the consideration of certain standards like OPC Unified Architecture.

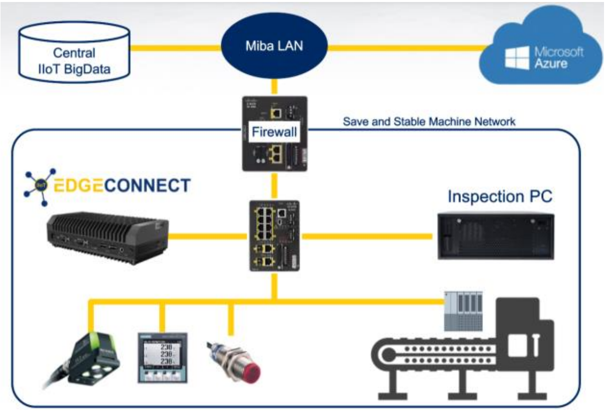

Figure 7: Miba IIoT Architecture

By having all this data in a structure form, analysis and interfaces to other systems easily can be established. With these possibilities new business models can bring value for the entire production process. Now for example specialist bring all data in relation to the production processes to find patterns and irregularities to reduce scrap rate.

One other use case how IIoT in combination with predictive maintenance will help, is to avoid unplanned downtime or achieve better planning of our production support processes. For example critical components have to be monitored constantly and replacements should be kept in stock.

3.2.5 Sputter Technology in combination with Artificial Intelligence

In collaboration between the Sputter Technology, the production and the IT team, an AI (Artificial

Intelligence) system has been set up. This system is already operative on most of the serial coating devices to support preventive decision making in real time for destructive testing avoidance.

Sputtering (PVD) technology is used in Miba to deposit the final running layer onto the surface of bearings and gears. To ensure a high product quality, destructive testing is carried out for all produced batches and therefore a significant number of parts are destroyed per year.

Due to the complexity of the process with numerous influence parameters an analytic correlation approach to identify out of range batches must be supported by high effort destructive testing after the coating process. Therefore, it has been decided to develop a data-driven solution. AI-based models have been developed to predict the quality of the parts. These models were trained from the historical data by using machine learning techniques. The AI predictive quality system is up and running, and it will be improved, evaluated and monitored continuously. The described Architecture in shown in Figure 8.

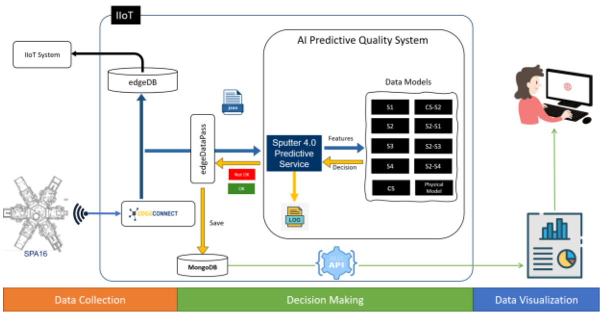

Figure 8: Sputter/AI Architecture

3.2.6 Automatization

Automatization is one of our key elements by our digital transformation. For instance, all processes will be reviewed regularly by the usage of data mining. It is easily possible to find out if processes are very complicated and not stable. For some of these insights Miba uses an ongoing approach for automating these processes by the use of technology to perform tasks without the need of human intervention. This can include the use of RPA, automated machines and computer software to perform tasks such as assembly, inspection, packing and inbound logistics. Automation can also include the use of control systems to monitor and orchestrate our appliances.

3.2.7 Data Analytics

Data analytics is a very essential ability not just providing information, but on a next level to suggest decisions. In this regards the prescriptive analytics is the branch which provides for a specific situation recommendation.

According to Gartner there are four layers which are helping to classify common use cases.

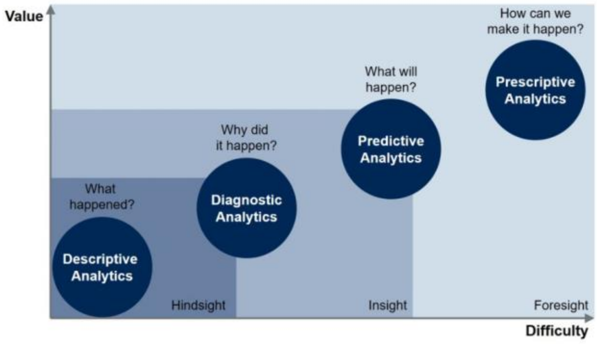

Figure 9: Gartner chart: From Hindsight to Foresight

At Miba we are focusing on all of these four layers. Nevertheless, we see a high potential in certain areas where we want to concentrate our activities e.g., identifying trends and insights, improving fraud detections and optimizing the supply chain.

Finally, the goal is, using data as an asset, minimizing human reaction, but predictive and proactive decision, with a high grade of automatization. An overview of the different grads of so-called analytic capabilities is shown on Figure 10.

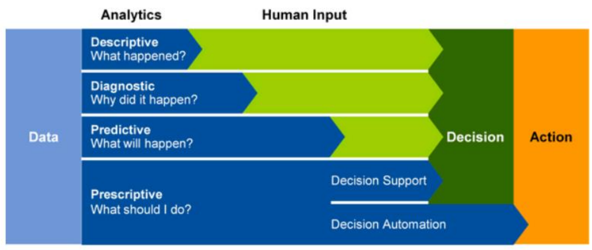

Figure 10: Gartner: Four types of analytical Capability

3.3 Bearing test rig references

For bearing type qualification and internal benchmarking for product development as well as product quality assurance bearing test rigs are used. The Miba Bearing testing department is operating 8 test rigs. For efficiency reasons and process optimization an oracle data base with a

Web interface has been set up covering the whole testing process from:

- the testing request by internal customers
- the test part production orders
- quality inspection documentation
- the test preparation (shaft / counterpart) preparation & documentation
- storage of testing results incl. recorder files and post testing inspection report

Today the established workflow / process has become a very essential asset. The data input is embedded in the testing workflow. A screen shot of a single process step is shown in Figure 11.

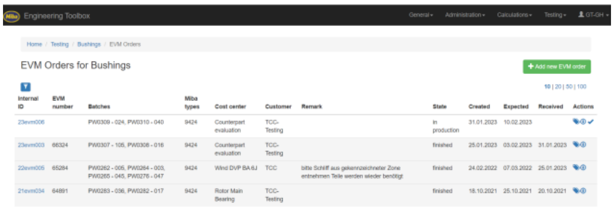

Figure 11: Web interface for quality check requests

Access with predefined roles is possible for all involved employees and internal customers, within the VPN. Needless to say that data as well as process mining is therefore easily possible. Depicted in Figure 12 an interactive result data evaluation is shown.

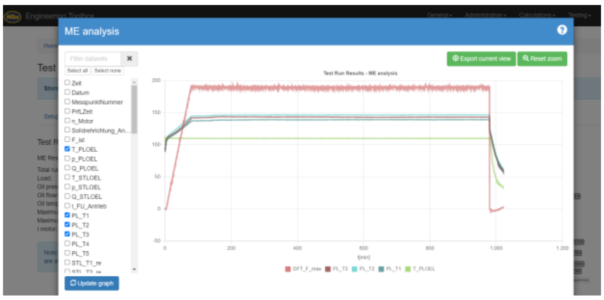

Figure 12:Test rig result, Data visualization

Up to date the benchmarking and multi test run result evaluation is done manually, which limits the data sets to be monitored. As there are more than 16.000 data sets available a machine learning approach for exploitation of the full data pool is the logical next step.

3.4 Bearing judgment and application data monitoring

All the efforts taken on process digitalization on layout, simulation and production side are open loop as long as the loop has not been closed consequently. In Miba´s case as component supplier the field experience of the products within the end-users applications is this loop closure.

During engine and bearing type development a DVP is set up in close cooperation with engine OEMs. This is of course essential for reaching a target validation level before high volume serial release. Field inspection of components are done rarely as costs for disassembly and down time are significant. Inspections during service and especially end of life are an option but most of the service staff is neither trained in bearing judgment nor do they have an easy to use tool for assistance. As a prerequisite for an inspection App Miba investigated the options of an image recognition system for the bearing judgment. For training of the machine learning algorithm experts pre-evaluated several hundred bearings.

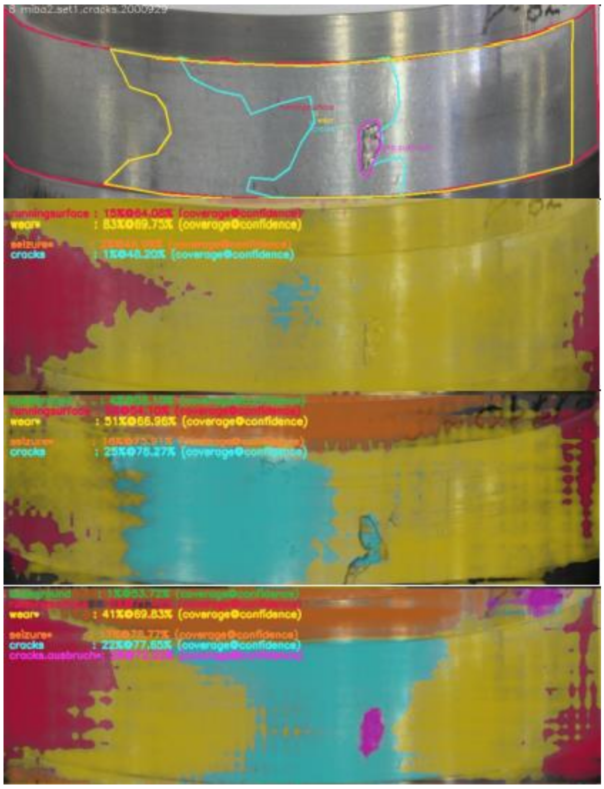

Figure 13: Development of the Algorithm stages from expert judgment on top to transfer learning in combination with customized loss function (bottom)

As visible in Figure 13 the correlation between the optical judgment done by experts to the final image recognition algorithm used is quite impressive for high quality pictures with uniform illumination. A sensitivity analysis with different resolutions and lighting settings turned out to significantly influence the AI based judgement result. As in service environment an adequate illumination and picture quality can´t be expected no further efforts have been taken for a bearing judgment app for the time being.

A different path to gain more application related data - to be correlated with production data - is the use of measurement data of condition monitoring systems. Actually, for the connection rod these systems are mainly used within the engine development (for risk mitigation and shortening development time) or for special applications, for health monitoring. In addition, indirect measurements are done with splash oil temperature sensors for medium speed engines.

With the maturity of all these monitoring systems, application related data volume will increase significantly. In combination with subsystem / component layout and production data down to the single part a holistic data picture of single bearing systems should be deduced. Anomaly detection, health monitoring and TbO prediction could be improved significantly.

Data exchange coordination can be executed via independent, non-profit platforms (as Mýa) for promotion of industry collaboration in realizing the benefits of digital technology [8].

4 TECHNICAL AND ORGANIZATIONAL PREREQUISITES

To optimally support the digital product life cycle engineering both technical and organizational prerequisites must be fulfilled. As the product life cycle spans multiple systems, they must be interconnected, and the involved people must be equipped with the right skills and tooling to work efficiently together.

4.1 Organizational prerequisites

With resource constraints on local markets, a shift to the global pool of software development experts is crucial. A diverse team, working in an agile way, with short sprint cycles is essential to identify issues early and spark new ideas.

To be truly successful, a different way of working is needed. Ideas need to be quickly prototyped and challenged by the domain experts in the application engineering area.

The exchange between the domains is important to identify necessary changes as early in the process as possible. Like physical products, changes late in the software development process become more expensive and harder to accomplish.

4.2 Technical prerequisites

Interconnectivity of systems and the global distribution of the users create certain challenges that must be addressed on a technical level to enable not only great user experience but also a good flow in the development process.

4.2.1 Software Interfaces

The first question to be answered during system integration is finding the right way to connect two applications. To ensure the toolchain can be properly integrated over the entire process, the systems involved need to support modern interface technologies.

Custom applications must expose their functions & data via application programming interface (API) standards such as REST [3] or ODATA [4]. This way the tools can easily be interconnected and avoid manual data duplication. This has huge impact on the efficiency of the development team, as they don't have to think too much about how the systems get connected, but which data should be exchanged or which function to be called.

As modern software solution usually consists of a JavaScript based frontend and an API based backend which brings a great deal of flexibility.

The user interfaces are all built on modern web frameworks such as Angular. These frameworks connect to a REST API in the backend and therefore you always build an application with an integration layer by default.

Connectivity to existing standard solutions also must be considered. If they offer other communication protocols an API based integration layer should be considered.

4.2.2 Data access and security

To enable our customers - anywhere in the world - to directly access our application layout frontend and collaborate with our engineers in a state-of-the-art workflow, we must follow a zero-trust [5] approach.

Zero-trust means we treat every request to the application as potentially bad. Hence every request must be authenticated, inspected by a firewall and input data validated.

Secure coding guidelines are a necessity to ensure high code quality and proper release workflows into production. The secure coding guidelines are continuously reviewed and adapted. For example, if changes to standard documents such as OWASP Top Ten [6] are announced.

Data Access also follows the lease privilege principle, so data is not excessively exposed.

Inside the application the Customer Data is separated and via a strict roles & rights management module ensured that no accidental data leaks occur.

To access our applications. a common Identity provider is used that also allows federated user logins from our partner companies. This means our customer's users login with their own company credentials. This has two major benefits. First the user doesn't need to remember a new password. Second, if they leave their company and their account is locked, they automatically loose access to our portal. Technically, we leverage Azure Active Directory four our internal users and B2B Guest accounts to grant customer's access to our systems.

Besides managing the access to data, also it's integrity must be ensured. Changes to data is logged in a change log and can be audited. To prevent data loss, regular backups are taken, and security measures established that allow a restore to a previous point in time.

4.2.3 System performance

The expectations of users have changed over the years when it comes to loading times of an application. In the distributed world, this challenge hasn't gotten easier as data still needs to travel the world. Global cloud providers, offer technical solutions that help tackle this challenge.

Hosting the applications in the cloud and using their backbones with solutions like Content Delivery Networks (CDN) [7] to shorten the distance from a user to the application is one step.

Further important steps to boost loading times are proper system design with features, such as lazy loading of components or smart caching.

Lazy loading for example only loads the data from the backend which is currently needed by the user. For example, if you show a table of data, you only load 30 rows which can be shown at once and if the user scrolls additional data is loaded from the backend.

Caching is also an effective method to reduce the amount of data travelling over the line. This is usually applied to static files such as images on the page or the JavaScript files that are used by the browser to render the page. This way if you load a page for a second time only a fraction of data needs to be loaded again.

For long running calculations on the other hand, asynchronous jobs are created with instant feedback to the user that the calculation has started. This allows the user to still navigate the page, without the need to wait until a calculation has been done. After the calculation is done the user is notified that he can now review the results.

The high-level architecture of our customer facing configuration solutions is shown in figure 14.

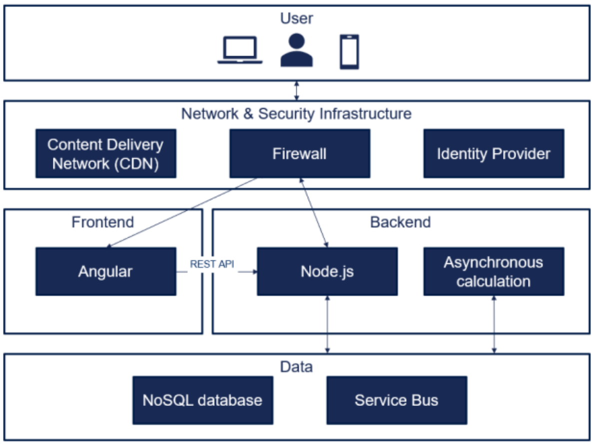

Figure 14: High-level architecture of the configuration engine

Important is that all access flows through the Network & Security infrastructure in the cloud. The Frontend & Backend are hosted on scalable cloud services and the Data layer is using platform as a service database modules.

5 CONCLUSIONS

Beside the focus on technology innovation, the digital transformation is a key element in Miba´s strategy to create Customer value in terms of tailored bearing solutions supporting leading application system. This strategy consists of two pillars, business model development and internal processes. DPLE tackles the aspects of both, as internal processes are optimized and streamlined using various digital approaches, but also the business aspects are covered using engineering platforms for time to market reduction. As described in the main sections the actual focus is on several "independent" projects, in the background the approach is to interlink the databases and use data mining tools for additional value creation. The systems developed and integrated are evolving to continuously increase the capability and benefit. However, individual digital elements accomplished years of operation, like the test rig database and the MES already and there is no doubt that they truly pay off. In certain product families the time to first product sample was reduced to 50%. Data consistency especially for complex global project organizations is guaranteed avoiding ineffective alignment loops. New product families can be based on AI driven virtual quality monitoring avoiding resource consuming destructive testing.

6 DEFINITIONS, ACRONYMS, ABBREVIATIONS

VPN: Virtual private network

OEE: Overall equipment efficiency

PVD: Physical vapour deposition

DVP: Design verification plan

RPA: Robotic Process Automatization

OPC: Open Platform Communications

IoT: Internet of things

IIoT: Industrial internet of things

AI: Artificial intelligence

EVA: economic value added

OEM: Original equipment manufacturer

CJM: Customer Journey Mapping

UI/UX: User Interface User Experience

TbO: Time between overhaul

MES: Maschine execution system

API: applicatoin programming interface

REST: **RE**presentational **S**tate **T**ransfer

ODATA: Open Data Protocol

CDN: Content Delivery Network

B2B: Business 2 Business

OWASP: Open Web Application Security Project

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