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Smart electric motor: Evaluation of business potential for digitalisation in the large electric motor industry

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Abstract

Digitalisation is seen to have contributed to the demise of 50% of the Fortune 500 companies since 2000. The large electric motor segment is not immune to this changing business landscape and must evolve to survive. This sector is experiencing declining revenues as traditional hardware-sales-focused business models have proved inadequate to address a reduction in profitability. New business models that exploit new digital value streams are to leverage the value from emerging technologies of the Industrial Internet of Things, Big Data and the associated emerging predictive analytics. These can be optimised via Cloud Computing and delivered utilising Platform as a Service software solutions to reduce cost and support scalability. The missing link in the justification chain for the installation of digitalisation packages on large electric motors is a model to determine if and which package sections return the most customer value and, therefore, sales opportunities for the supplier. In this context, this paper introduces the concept of the smart electric motor. The focus is on the oil and gas industry, where digitalisation is already deeply engrained in practice and shows how risk-based decisions can deliver a profitable project through new business models and digitalised solutions to reinvigorate this traditional industry.

1 | INTRODUCTION

In 1963, Leon C. Megginson summarised the sentiments of Charles Darwin's Origin of Species with "It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change". He was of course referring to the natural world; however, this sentiment can be applied to modern industry and the inevitable drive towards digitalisation. It has been said that digitalisation is the main reason just over half of the companies on the Fortune 500 have disappeared since 2000 [1], and it is estimated that this trend will continue into the future. For such companies who produce large electric motors (LEMs), this is a risk, which must be addressed to remain competitive.

Although the digital transformation of the LEM industry is still in its infancy, the oil and gas (O&G) digitalisation expenditure is already significant; in 2015, the sector spent $7 Billion on Internet of Things (IoT), $6 Billion on cloud services and $ 3.5 Billion on Big Data, which are all expected to increase significantly by 2020, as shown in Figure 1.

The O&G industry faced significant challenges over the past years since the oil price (West Texas Intermediate) dropped from over $100US/bbl in August 2014 to below $30US/bbl by January 2016 when adjusted for inflation [3]. This has resulted in the O&G companies reducing expenditure and placing more pressure on the justification of project funding [4].

A linking element in the digitalisation of LEM business models is presented in this paper: the net present value (NPV) of a digitalisation project. This paper defines LEMs as those over 375 kW and will address the question: Can digitalisation increase value in the LEM segment and reinvigorate this old industry? To address this question in more detail, the variables that have the most significant influence on a digitalisation project's value have been identified and evaluated, and the variables have been assigned to either the customer or supplier as they are responsible for obtaining this data. The key variables have been evaluated as to how easy or difficult this data is to obtain as this is the final step in realising the potential of a digitalisation project for LEMs.
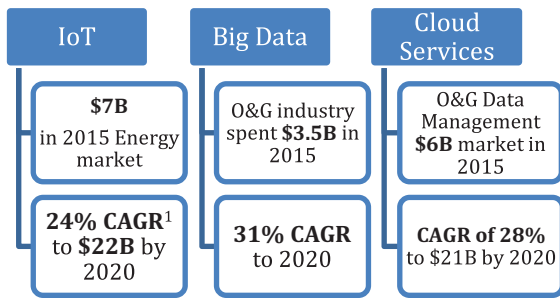
FIGURE 1   O&G IoT, Big Data, and Cloud Services expenditure [2]

The missing link in the justification chain for the installation of digitalisation packages on LEMs is a model to determine if and indeed what sections of a package return the most value to the customer and therefore sales opportunities for the supplier. A customer value model that addresses the missing piece of a calculable NPV for a digitalisation package for LEMs was developed to provide the end customer with a justification for the digital solution investment.

The business opportunity is driven by both the value to the customer and the value to the supplier as the digitalisation of LEMs has very different value streams, depending on which side of the partnership you are on. It is critical to understand both sides of this equation in order to fully develop and exploit the value in the digitalisation opportunity. Once the different value streams have been identified, the key value of the associated customer process is fed into the model for a real-world case study. This uses existing technology and plant and the interaction between a supplier's hardware and software costs, and a customer's process value stream. In the worked example, the liquefied natural gas (LNG) throughput is used. Sensitivity analysis of key quantities is finally performed, analysed and conclusions drawn.

2 | RESEARCH STATUS

2.1 | LEM suppliers and digitalisation

Due to the extremely rapid rate of change within the digitalisation business world, this paper focuses on both recent business white papers and industry publications as well as academic literature on the subject. A key piece of research has been produced by the World Economic forum entitled "Industrial Internet of Things: Unleashing the Potential of Connected Products and Services" [5]. The report predicts that the IoT revolution will drastically alter the manufacturing, energy, agriculture, transport, and other industrial sectors over the next 10 years. These are industries that together account for two-thirds of the global gross domestic product. It finds the industrial Internet to be transformative and predicts unprecedented opportunities with the Industrial Internet of Things (IIoT) along with new risks to business and society [5].

Both Siemens and General Electric misjudged the growth in both the large electric drive market and gas turbine market in

their power generation units. As such, both companies have had to adjust their associated business units. Siemens has proposed in 2017 a 6900-person reduction [6] and GE a 12,000-person reduction [7]. The Siemens MindSphere paper has a focus on the IoT and the connection of the real world with the virtual world of data. They propose an underlying structure of Software and Services, overlaying the MindSphere cloud IIoT operating system to enhance their separate business units, including power generation and the O&G industry [8].

The ABB whitepaper also provides an O&G digitalisation focus. Their method is to allow O&G companies to get a highly granular view of their assets, which, when viewed in conjunction with data from more traditional business systems, can generate quicker and better insights to drive competitive advantage [9]. Again, the focus is that for companies to benefit significantly from the potential offered, they will need to embrace digitalisation on a bigger, much more holistic scale encompassing end-to-end processes throughout plants across the supply chain—not just in isolated pockets of change. This is a common theme among companies; however, it should also be highlighted that there is a significant financial benefit to the companies selling the digitalisation solutions. It will be incumbent upon them to deliver business solutions with verifiable results through concrete financial reporting, such as an improved project NPV, which is currently not in place and the subject of this paper.

Schneider Electric breaks the transformation of the O&G industry business models via IIoT concepts down into three key factors: decreasing cost of connected sensors, increased connectivity, and new software analytics utilising real-time data [2]. The paper claims that the backbone of the transformative IIoT trend is the linkage of connectivity, cloud and analytics technologies to simplify process automation [2]. The paper also highlights that there are "opportunities to link multiple platforms operated remotely from a single onshore centre or to deploy remote monitoring for onshore and offshore operations can dramatically reduce the need for physical on-site inspections". While this statement is correct, this is not new to the industry and certainly not unique to Schneider Electric. The Australian O&G company Santos, amongst many others, implemented such a program for their onshore gas fields over a decade ago, more recently also including full video conference facilities at their remote partially manned field locations, which required a fibre-optic cable to be laid with the trunkline to enable an Internet connection in an otherwise off-grid location.

GE's Playbook white paper boils down digital industrial transformation into five key pillar initiatives: capabilities and operating model, platform, partner ecosystem, digital talent and culture, and business model innovation [10]. This paper has its main focus on capabilities and business model innovation as it applies to the LEM segment specifically. The paper states that the current age of the digital industry is marked by ever more powerful software and falling hardware costs. That is, today's predictive algorithms and machine learning capabilities enable use cases that were not possible even five years ago. This is a common theme throughout all four companies' white papers. A key piece of market research performed by GE in October 2017 found that the importance of the digital transformation

TABLE 1 To what degree do you consider the following to be a barrier to Digital Industrial Transformation? [13]

	Power/Energy	Utilities
Base size	*n = 50*	*n = 50*
Investment costs	40%	36%
System security concerns	40%	40%
Data privacy concerns	36%	34%
Operating costs	26%	26%
Legacy systems/technology	42%	28%
Lack of clarity on return on investment	26%	36%
Lack of qualified workforce/skillsets	40%	16%

was ranked highly at 78.3% for the outlook, against a company readiness of 55.2% and a workforce readiness of 63.4%. This shows that the companies are aware at some level that there is significant work to be done in order to reach their digitalisation goals [11]. All four companies have their own next generation software platforms—Siemens MindSphere, GE Predix, ABB Ability, and Schneider Electric has EcoStruxure—to facilitate the digitalisation of LEMs [12]. The importance of collaborative relationships in business markets are common themes for customers and suppliers alike. Customers need to decide whether to invest in a new supplier relationship, to maintain and develop a valued relationship, or to divest from a low-value relationship [13]. While all four companies have an extensive digitalisation road map, with comparable drivers and motivations, what none have provided is a concrete path to deliver a LEM digital strategy to identify and deliver the different value streams made possible by the digital infrastructure for the O&G industry.

2.2 | LEM customers and digitalisation

The key LEM sectors of power/energy and utilities believe that between 54% and 58% of both the individual companies and the overall industries are primarily responsible for ensuring that the workforce is ready for the demands of IIoT [11]. This aligns with the proactive approach seen in the leading companies' white papers [2, 8–10] as well as the World Economic Forums industry overview [5]. Collaboration between the industry, their partners, and clients can be regarded as the backbone of valuable business decisions as input from both the customer and the supplier is required to deliver a successful project.

A successful digitalisation program is bound to IT functionality; however, the level of integration will also depend on the roles those the company performs internally and those that are contracted out. For example, if the LEM digitalisation analytics are all performed externally via cloud platforms, the integration of internal IT personnel is potentially less important than if they are performing the same analytics in-house.

Common to both power/energy and utilities are investment costs of 40% and 36%, which can be seen in Table 1. The investment cost barrier being one of the highest across the industries shows the need for a value proposition that addresses the costs

of a system as well as the value, and this will be addressed in this paper. System security concerns and data security are also ranked highly as barriers. This is a common theme throughout the companies' white papers as well as the World Economic Forum document. Contrary, however, to this concern, Armbrust et al. claim that "…there are no fundamental obstacles to making a cloud computing environment as secure as the vast majority of inhouse IT environments" [14].

Due to the extremely fast-moving nature of digitalisation, expert interviews were required to fill gaps in the official publications. Six experts from the LEM industry were interviewed to fill in gaps identified by the literature review. Open questions were used to allow adequate breadth of discussion and give the experts the flexibility to get to the root of the question from their professional positions.

3 | METHODOLOGY

Both a literature review and expert interviews have been conducted to obtain the necessary information to perform analysis on both the customer and supplier value models proposed for digitalisation of LEMs. Industry analysis has been done to provide further qualitative insights into value streams, which are outside the scope of the case study. The case study quantitative and qualitative analysis as well as industry analysis are finally combined in the results.

3.1 | New value models: Why invest?

The missing piece for the justification for the installation of digitalisation packages on LEMs is a model to determine what sections of a package return the most value to the customer and, therefore, sales opportunities for the supplier. With this justification, a model has been created with the inputs labour charge-out rates, OPEX and CAPEX costs as well as downtime improvement likelihoods from the supplier. The customer inputs are the number of installed units, process value, and historical maintenance data. It is tailored specifically for the O&G industry, where the concept of deferred production rather than loss is at the core of the business. The model output is divided into two key sections: Decision Tree for Digitalisation Selection and Sensitivity Analysis.

The Decision Tree has been designed to accept the input variables from both the supplier and the customer to determine the most efficient digitalisation installation. Depending on the input variables, the output will determine which units justify the installation of a digitalisation package and ultimately, the NPV of the project. This will, therefore, provide the customer with concrete financial justification and a starting point for project kick-off. This will change the sales pitch from "we can provide potential savings" to "from the values you have provided, we will save you this amount of money over the next five years".

The uncertainty in many of the input variables means that it is critical to evaluate the relative importance between them. This provides value to both the customer and the provider as the dependent variables need to come from both parties and,
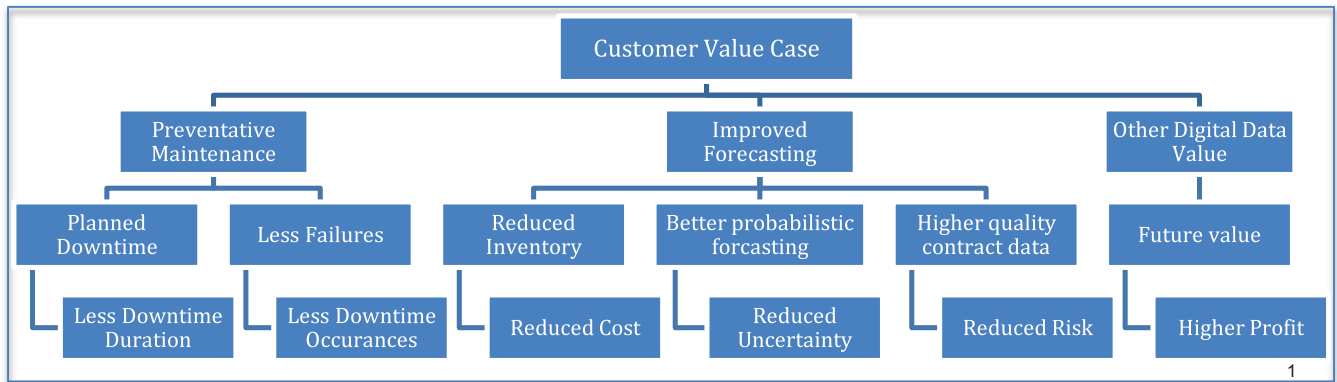
FIGURE 2   Customer value proposal (Own figure.)

hence, will have a contributing factor on the final project justification. The analysis will, therefore, highlight which variables are more important and, therefore, warrant further investigation and potentially upfront resources to reduce the uncertainty in the final project NPV.

The supplier value model has been reviewed as the second half of the overall value model. The supplier has different value drivers than the customer, and the interactions of these two parties are required to deliver a successful project. Some value streams are clear for the supplier: payments for hardware, software, and services. The other value streams such as those involving big data and digital twins are more complicated and are addressed separately.

3.2 | Industry analysis and case study

Industry analysis for an example O&G facility was conducted and broken down into both customer and supplier project justification. This breakdown is required as for a digitalisation project in the O&G industry to proceed on LEMs, there must be a viable value case for both sides of the sales agreement. The customer project justification is broken down into the three key subsections: preventative maintenance, improved forecasting, and other digital value. The supplier project justification is segmented into hardware, software, and leveraging value from data.

To prove the value behind a digitalisation business case, a case study was conducted on the Snøhvit LNG plant in Norway, a European example of the interaction between a LEM fleet and a process with significant value. The case study looks at how the LEMs interact with the process they drive, the value intrinsic to that process, and deferred production as a key value driver. This addresses the case quantitatively with a calculable value. The process and digitalisation improvement values are then fed into the value stream calculation. The tool chosen is Excel as it has enough flexibility for the calculations to be re-run for a different customer and can perform sensitivity analysis. The quantitative analysis will focus on the customer's process value streams in combination with the supplier's costs and digitalisation deliverables and a concrete calculation of the projects NPV.

The approach will include sensitivity analysis on critical variables due to the uncertainty and variability of company data as well as business sensitive data, which cannot be released.

4 | MAIN SECTION

The success of LEM digitalisation sales is based on two views: the customer and the supplier. Both parties must be satisfied with their value propositions for a successful digitalisation project to be delivered.

4.1 | Customer value case

The customer value case is broken down into the key subsections, as shown in Figure 2: preventative maintenance, improved forecasting, and other digital data value.

To make a significant investment in the digitalisation of LEMs, the customer will require proof of the value that the smart LEM will add to their business. This will include items such as increased reliability and decreased downtime through preventative maintenance, lower gas market risk, and reduced inventory through increased forecast accuracy. The key to this value proposition is the role in which the LEM plays in the overall drive train and ultimately the process for which it delivers power.

The value in smart motors is not limited purely to the value of the motor itself. In fact, a focus only on the value of the LEM would typically not be justified as a stand-alone project. As discussed in the case study in Section 4.3.2, a €2 million motor can be critical equipment powering a €2.4 million per day process. The value of the electric motor alone is here not a significant proportion in the O&G value stream. The process that is driven by the LEM, however, can be critical to the financial health of the company.

In the case of the O&G industry, planned downtime via preventative maintenance is a key piece of the value-add position for a LEM digitalisation project, where a potential problem can be identified and the organisation given time to thoroughly plan for the maintenance activity. This typically results in a
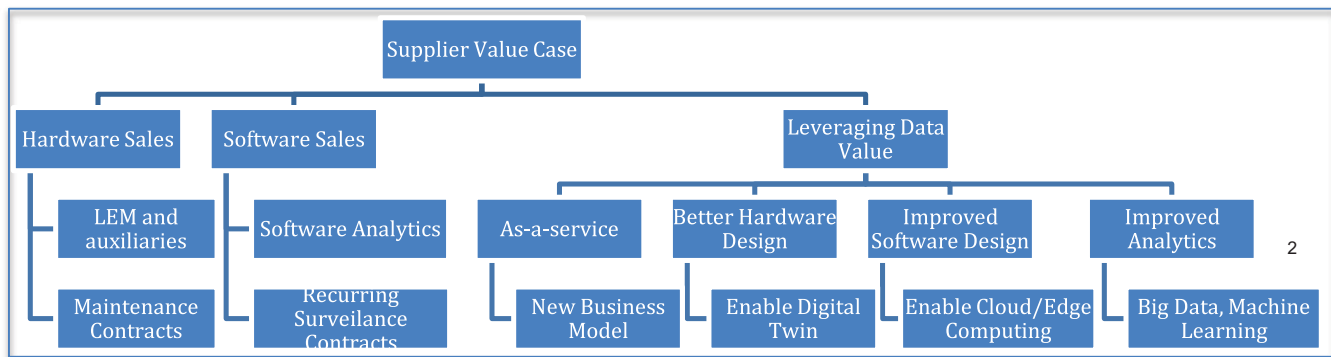
FIGURE 3 Supplier value proposal (Own figure.)

reduction of total time the equipment is out of service as the correct personnel, equipment, tools, and process conditions can be pre-prepared. In the case of remote areas such as remote Central Australia or offshore platforms, this can be a significant saving. This is confirmed in the case study, which shows the considerable value realised by reducing the downtime duration of an event just by a few days over many years. This reduction in reliability and availability uncertainty allows for improved forecasting of the process. Further to this, less maintenance personnel are required on permanent staff if there is a lower likelihood of unplanned maintenance, where contract employees can be brought in for planned maintenance outages. Improved forecasting can also significantly reduce inventory requirements.

As per many primary energy sales, an LNG provider may have a contract with a specified energy value or tonnage to be delivered by a pre-defined date. While all contracts are different, it is common practice that a penalty will be built into the contract for delayed delivery. The likelihood of this penalty can be reduced by increased forecasting capacity with a digital condition-based monitoring system. Probabilistic forecasting from digitalised analytical techniques can result in increased confidence in results, fewer data exceptions, more time for strategic planning, and the ability to analyse multiple "what–if" scenarios [15].

The final value in the digital data is much harder to quantify, but it is conceivable that it will eclipse the direct value on the production stream. This value stream includes future uses of the data which may not be clear. This could include improved process facility designs, augmented inventory systems or any number of future data analytics development. The process of gathering data has the potential to help identify these future data streams as the smart motor industry matures.

4.2 | Supplier value case

The supplier value case is broken into hardware and software sales, as well as leveraging data value, as shown in Figure 3.

Traditionally, the large drive sector has focused on hardware sales as their primary income stream. This business model has remained relatively unchanged over the past century with the

sale of hardware being the basis for the profit margin. Secondary to this, maintenance and service contracts have played a supporting role.

Hardware sales of large drives have been decreasing, for example the departments of "Process Industries and Drives" at Siemens saw orders drop from 9.1 to 8.9 Billion Euro [16]: Oil and Gas" at GE which includes synchronous and induction electric motors saw equipment orders fall from US\$6.6 Billion to US\$3.7 Billion [17], and Discrete Automation & Motion at ABB a fall in orders from \$9.2 Billion to \$8.7 Billion [18]. Each of these companies mentioned declining sales of electric motors and exposure to the lower oil price being significant contributors to this decrease. Digitalisation provides an opportunity to reinvigorate the old industry of LEMs by leveraging new value streams outside of the traditional hardware-based model.

Major manufactures have the capacity to deliver scalable software solutions for customers with almost flat marginal costs. The scalability is an advantage for customers who otherwise would have to set up the solution individually. This then opens the opportunity to provide recurring surveillance contracts, where LEM experts from the supplier can monitor and report on multiple assets from many companies. The in-house knowledge of the motors is also a competitive advantage and a valuable resource, which is already being realised: Revenue FY 2016 for Siemens in software solutions and digital services combined increased by 12% over the previous financial year, with revenues of 3.3 Billion Euros in software and 1.0 Billion Euros for digital services.

The key to a successful digitalisation business is the move from data to information, which leads to insight, facilitates action, and delivers impact [19]. The way gathered data and sensors are used can vary greatly, but the overarching tenant of moving from digital data to value is common. The new digitalisation business models are broken into four main trends that exploit these opportunities: As-a-service business models, platforms, intellectual-property-rights-based business models and data-driven business models [19]. As-a-service business models for LEMs could be the opportunity to sell power or energy, rather than the current hardware/software sale model. Critical to this model is the data gathered from LEMs, as the reliability improvement due to digitalisation is the value driver for

TABLE 2 LEMs in process stream [20]

	Size (MW)	Function
Motor #1	65	Gas refrigeration compression for LNG
Motor #2	65	Gas refrigeration compression for LNG
Motor #3	32	LNG boil off compressor
Motor #4	16	CO_2 compression

such a model. Both direct and indirect monetisation of data are possible. The best example of direct monetisation of data is Google where the search engine produces data as a primary product, which is then further analysed for targeted advertising, can result in a revenue stream. The LEM segment sits in the second category: indirect monetisation. The data can be used to improve the software systems or indeed the hardware itself. An example of this is the "Digital Twin", which allows for a digital simulation to be created to predict future behaviour of the LEM.

This then has the potential to provide valuable feedback to the manufacturing process: new materials, designs, and dimensions can be considered digitally before any change to the manufacturing process is considered. The data can also be used to evaluate improvements to the software or analytics. Estimations on temperature or vibration profiles, for example, can be measured and evaluated with Big Data through machine learning algorithms to reduce the engineering tolerances required in the software shutdown or monitoring system. This is then a continuously improving feedback loop with the analytics improving as more data under more varied conditions is obtained.

There are clearly challenges associated with the gathering of customer data. What is certain, however, is that the benefits of digitalisation of LEMs need to be perceived to outweigh the risks of such a program, to allow the business plan to succeed. In order to move from a hypothetical case to a concrete solution, the following section will detail a real-world case study.

4.3 | Case study

The target market for the initial implementation will be assumed to be the O&G industry. This is a good basis for studying follow-up markets, including electricity generation, mining, and shipping. The O&G market has an existing knowledge base comfortable with making risk-based decisions as well as large value streams dependent on the reliability and availability of the large drives in the compression drivetrain. For example, a LEM has an approximate replacement cost of 2 Million Euro; however, the process in an LNG plant may have a value of over 2.4 Million Euro per day. This makes the value proposition compelling.

For this case study, data has been gathered for the Norwegian Snøhvit LNG plant and used as the basis for the case study. The plant has four LEMs, as described in Table 2.

4.3.1 | Driving the process, the application of LEMs

The 16-MW CO_2 compressor is used to re-inject produced CO_2 back into the gas reservoir, which can serve the dual functions of maintaining reservoir pressure in the gas field as well as a way of storing CO_2 to reduce emissions to the atmosphere [21]. The injection of CO_2 is an important part of the process, both financially and environmentally. However, due to complex reservoir property interactions, CO_2 injection is not as time critical as the other processes.

The 32-MW gas boil-off compressor takes the methane that boils off as part of the process to maintain the low temperature of the LNG and re-compresses and cools the gas back into the liquid state at approximately −161 °C [22]. This compressor is, therefore, a critical piece of equipment for the LNG process; however, the complex interactions between the boil-off compressor and process are outside of the scope of this study. For this reason, the two 65-MW compressors will be the focus of the quantitative section of the case study. These two compressors are responsible for supplying the compression to feed the LNG process and, therefore, can be directly linked to the process availability.

4.3.2 | Process value

The value of the LNG process is driven by the two LEMs #1 and #2 in Table 2 and can far exceed the value of the individual machines. They are, therefore, critical pieces of equipment, and the reliability and availability of this kit is, therefore, of high value.

The Snøhvit LNG facility is estimated to produce approximately 4.3 million tonnes/year of LNG, 747,000t of condensate, and 247,000t of LPG [21]. Taking the largest value stream of LNG and assuming a conservative price of US\$4.9/MMBtu [23], a heating value of 53.38 MMBtu/tonne [24], with the density of 451 kg/m^3 [24], gives 4.3*10^6 x 53.38×4.9 = 1.125 Billion US Dollars per year. This is approximately \$3 million US dollars per day or 2.4 million Euro per day. When compared to the price of an individual 2 million Euro LEM, it is clear that the value to the company lies in the process, not the motor itself.

The facility also contains storage in the form of two 125,000-m³ LNG tanks, one 75,000-m³ condensate tank, and one 45,000-m³ LPG tank. This storage then equates to approximately 9.5 days of LNG production. This is significant in the value calculation as it may, therefore, be possible to build up LNG inventory in the tank in a planned maintenance schedule to continually load the LNG transport during the plant outage. This means 9.5 days of buffer in the planned maintenance case, with 4.75 days assumed for unplanned maintenance (assume average ullage of the tank at 50% full). This base case says that for every unplanned incident, which is transferred to a planned incident and conservatively holding all other variables constant, the ullage factor alone could be valued at approximately 4×2.4 million Euro = 9.6 million Euro. This shows that the assumed duration reduction of downtime of one day assumed in the case
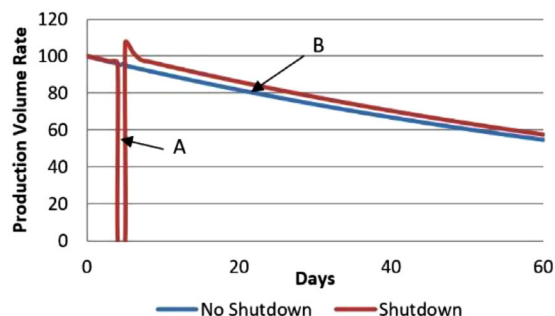
FIGURE 4 Example gas well production (Own graph.)

FIGURE 5 Example LNG plant production deferral (Own graph.)

study is likely to be conservative and would need to be updated with specific data regarding the plant-specific and complex interaction between customer, market, shipping availability, tank ullage, and downtime.

4.3.3 | Deferred production

Production outages in the O&G industry are often considered deferred, rather than lost. This is because the hydrocarbon as a product still exists and is likely just to be recovered later. O&G reservoirs also exhibit transient pressure characteristics. This means that a shut in well will produce at a higher rate after a shutdown due to the reservoir pressure beginning to stabilise, and the resultant near well-bore pressure is increased [25]. The increased near well-bore pressure in turn increases the flowrate and thus some of the "lost" production is quickly recovered. An example of this behaviour is shown graphically in Figure 4. This is dependent on complex reservoir and fluid properties and interactions and requires highly complex reservoir simulations to predict the precise behaviour.

For the trivial example above with a standard logarithmic decline, despite the two days of lost production being equivalent to 8% of the two months production (area "A"), the increased rate after opening the well back up results in deferred production of only approximately 1% (area "B" – area "A") by the end of the production period. This is significant as while the total production volume produced does not change significantly, the time value of money has a significant impact the further into the future the production is pushed.

For the LNG processing case, the limiting factor is the LNG plant capacity, rather than reservoir performance, and hence, a linear production profile can be assumed. Thus, a production deferral can be assumed to be the train capacity. An example linear profile is shown in Figure 5.

The deferred production is assumed to be produced at the end of life of the train, which may be some 30 years. In Figure 5, the deferred plant production A is produced in a much shorter time in section B at the plants rated capacity. This is a conservative position as it can also be argued that the plant end-of-life is set, and the production value will indeed be lost, rather than deferred. The NPV of the deferred production time can be seen in Figure 6.
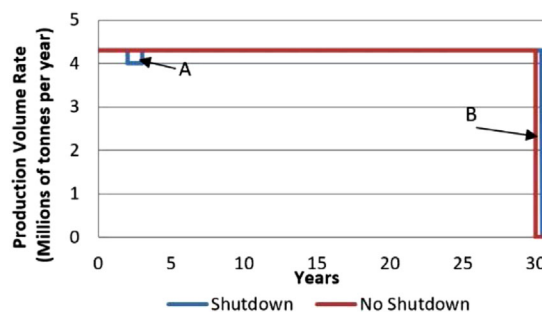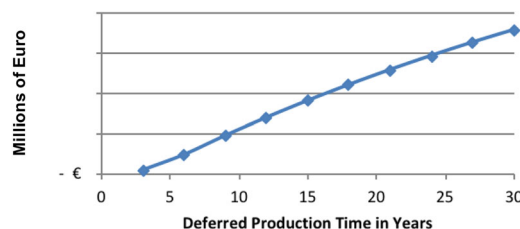

FIGURE 6 Deferred production time versus NPV sensitivity (Own graph.)

4.3.4 | Value stream calculation

To justify to an O&G company the installation and implementation of a digitalisation package for LEMs, it is incumbent upon the service provider to prove the justification of the expenditure. To calculate this value, a tool was developed with the following four stages: Background Data, Customer Input, Sensitivity Analysis, and Decision Tree. The details of the tool tabs are summarised in Table 3

4.3.5 | Background data

The Background Data section allows the supplier to input the required metadata, which is not viewable by the customer. The onsite support cost, motor/drive/gear digitalisation options, and the associated hardware are included. These options are each assigned a recurring annual OPEX cost in Euro and a once off upfront CAPEX cost.

4.3.6 | Customer input

The Customer Input section is the first point for the customer to begin inputting data (see Figure 7). Section A contains data that pertains to the current customer installed equipment and historical reliability data. The customer will be required to retrieve this data from their computer maintenance management system (CMMS) [26]. For new installs or for companies lacking this data, the supplier will need to have recommended generic inputs. This is especially important for green-field analysis as historic CMMS data may only exist for other service conditions, if at all.

TABLE 3   Digital package decision tool summary

	Inputs	Outputs	Basis
Background Data	Provider: Digitalisation OPEX / CAPEX Onsite support costs	Calculates cumulative costs and savings	Core data from supplier on digital package
Customer Input	Customer: Installed equipment, digital package config, process and reliability data	Deferred production, direct costs and savings	Data required from each process and setup
Sensitivity Analysis	None	Sensitivities on variables	Show which variables are significant
Decision Tree	Customer: Split of responsible unit from downtime	Best financial decision for digital installation	Show which options to install

Own table

Section A

Customer Current Situation

Number of Motors	2
Number of Drives	2
Number of Gear Units	0
Incidents per year with deferred production	0.15
Average duration of deferred production incident	8
Calls for technical support on site per year	0.2
Average duration of technical support onsite including travel	1.5

Section B

NPV Discoun Rate Assumptions

NPV calculation discount rate	2%
No. Years production deferred (expected train lifetime)	20
Deferred production (Euro/day)	2,400,000 €
Deferred process production loss (Euro/day)	784,869 €

Section C

Configure

		OPEX/year	CAPEX (once off)
Motor	Large (>10MW)		
Drive	Large (>10MW)		
Gear Unit	Large (>10MW)		
Hardware	Advanced		
Totals			

Section D

Analytics Savings

Reduction in onsite support (days)	0.5
Cost savings Euro per year	
Avoided Production Losses - Occurance (%)	20%
Avoided Production Losses - Occurance (Euro)	
Avoided Production Losses - Duration (days)	1
Avoided Production Losses - Duration (Euro)	

Section E

Costs Summary - Initial Conditions

Costs for reactive on-site support (Euro/year)	
Deferred production per year (Euro/year)	941,843 €

Savings Summary - With Digital Package Selected

Costs for digital package (Averaged over 5 years)	
Deferred production per year (Euro/year)	602,779 €

5 Year Costs	
5 Year Savings	7

FIGURE 7   Customer input tab (Own sheet.)

Section B includes the assumed discount rate, the daily deferred production rate, as well as the assumed years of production deferral. These three inputs are utilised to calculate the daily deferred production loss in Euro. This is a key input into the final project NPV.

Section C requires the selection of digitalisation products, depending on the size of the installed motors, drives, and gear units. These dropdowns are drawn from the data table in the Background Data tab and total the recurring OPEX and once-off CAPEX cost.

Section D requires the final inputs with some of the key variables that provide the value case for the installation. As will be seen in the following section, the avoided occurrence and duration productions losses are key metrics. These values will need to be provided by the supplier as it is unlikely the customer will have any reference values for such a system.
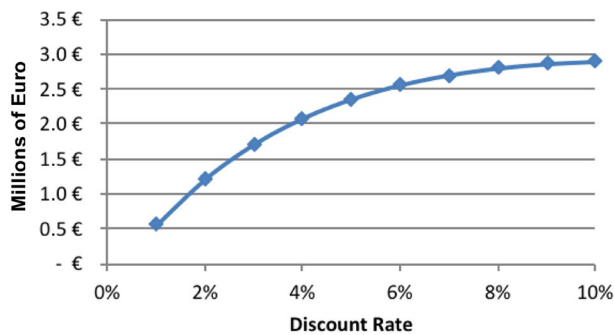
FIGURE 8 Discount rate versus NPV sensitivity (Own graph.)

FIGURE 9 Downtime duration versus NPV sensitivity (Own graph.)

FIGURE 10 Reduction in downtime occurrences versus NPV sensitivity (Own graph.)

Finally, Section E is a simple summary of the costs of installing the chosen digitalisation package and nominal savings. The downtime split between units and the project NPV are calculated in the decision tree tab, which is detailed in the decision tree tab section.

4.3.7 | Sensitivity analysis

Sensitivity analyses have been performed on the ten controllable variables. The results can then be broken down into three separate groups: low-priority variables, supplier priority variables, and customer priority variables.

The low-priority variables include number of tech support calls, duration of tech support calls, and reduction of tech support calls. These three variables have a minimal impact on the NPV of the project due to the relatively minor labour cost of having a technician onsite. There is, therefore, minimal value in the customer focusing attention on reducing the charge-out rate or the duration or frequency of the call-out, which needs to be treated separately here from the duration of the process outage, which is a different value stream.

The variables that influence the project NPV and are provided by the supplier include the discount rate, number of downtime incidents per year, the average downtime duration, the deferred production time, and deferred production rate. The discount rate is an assumption that can be made for the future lifetime of the project and is not project specific. Because of this, this variable may be an assumption by the supplier or more likely, an existing internal number the customer uses in all projects. This value will also depend on the project location and country inflation rates.

It can be seen in Figure 8 that the NPV of the project increases non-linearly with an increasing discount rate and that a conservative value of 2% has been used in this example.

As shown earlier in Figure 6, the deferred production time is a near linear relationship, with loss increasing with time. A similar linear relationship can be seen with the deferred production rate, and the NPV value can be seen to be nearly directly proportional to the value of the production stream, which is deferred.

Both the downtime duration and downtime incidence occurrences have a non-linear profile, and this data can be gathered from the cust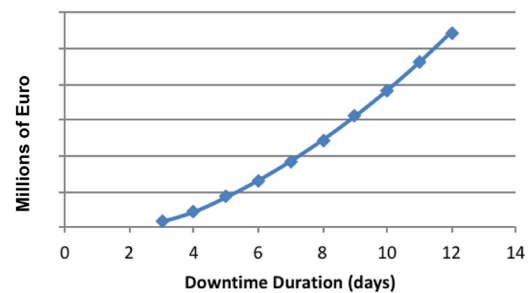omers' CMMS system or, for new installations, an estimate would be required from the supplier. The sensitivity on the downtime duration term is affected by the percentage avoided production losses; hence, an increase in downtime has a larger, non-linear impact on the NPV, as seen in Figure 9. A downtime incident of eight days has been assumed; however, it is also clear that a failure requiring an unplanned replacement of motor or drive would be considerably longer, possibly many months. The best method for obtaining this value would be through gathering of historical data from the customers' CMMS system.
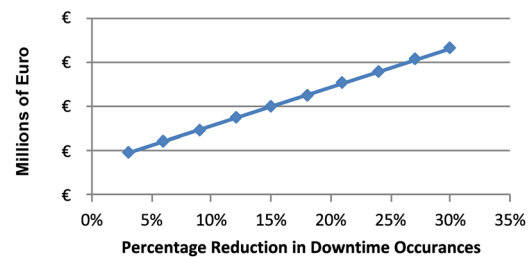
Downtime occurrences are similar, with a plant seeing less downtime indents obtaining less value from the digitalisation package, as seen in Figure 10. An occurrence of 0.15 times per year, or once every 6.6 years, has been assumed in the example case.

4.3.8 | Decision tree

The final data input area consists of two sections, the decision tree summary section and the decision tree, as shown in Figures 11 and 12. The summary section required the input split for the responsible unit. This breaks down the Savings Attributed, CAPEX, and OPEX costs into its separate parts, depending on which units have previously been selected in the Background Data section. The graphical representation on the right shows this breakdown. The Combined Costs are then calculated for each possible permutation of drives, motors, and gear unit digitalisation packages. This data is required to optimise the digitalisation package install options in the decision tree.
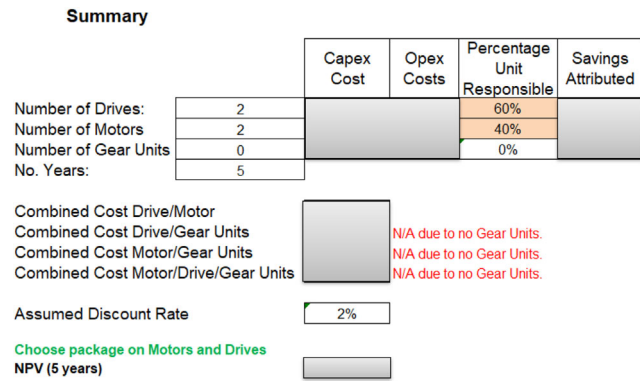
FIGURE 11 Decision tree summary (Own figure.)

field installations. Discount rate has a high ease of data acquisition as the company will typically have an existing number used through the company. Downtime incidents, downtime duration, and deferred time are relatively easy to obtain in a brown-field example as they should exist in the CMMS system; however, green fields would need to rely on data from other installations or companies. The deferred rate is typically a known value from the process value in either green or brown fields. Tech-support calls and duration are also easier to obtain from existing fields; however, a good estimation from other locations is also possible for green fields. The reduction in tech support callouts from a digitalisation program is more uncertain; however, this has little influence on the end project value. For the reduction in downtime occurrences and avoided downtime, the data is more difficult to obtain as this is the change from the digitalisation installation. This data must be supplied by the supplier and is also of high importance to the end project NPV.

In summary, the customer has three variables, which are of high importance and a medium ease of data acquisition: Downtime Incidents, Downtime Duration, and Deferred Time for green field applications. The supplier should focus on the two variables Reduction in Downtime Occurrences and Avoided Downtime, which are of high importance and are difficult to acquire for green fields, or medium difficulty for brown fields. The importance on these variables shows that innovative business models may be required to obtain this data: free or reduced cost hardware, software, or analytics could be offered, for example, to increase the data acquisition rate.

The final decision tree calculation shown in Figure 12 is the cumulation of all data and calculations in the sections Background Data, Customer Input, Sensitivity Analysis, and Decision Tree Summary.

In this case study, digitalisation on motors has an increased value, also for the drives. As no gear units have been selected in the Background Data tab, this is not included. The final recommendation is then included in both the Decision Tree and Decision tree summary to "Choose Digital Package on Motors and Drives".

The most significant final calculation is the project NPV. Here, the calculated NPV is over 1 million Euro when applying the digitalisation package to both the electric motors and drives. This analysis shows that digitalisation projects of large drives can be justified when the true value behind the whole process is considered. This can, therefore, form the basis of new business models, focused not only on pure hardware sales, but other digital value streams as well. This has the potential to reinvigorate the LEM industry by exploiting these market opportunities.

The summary of the multi-variable sensitivity analysis in Table 4 highlights the key variables that should be focused on, for the customer and the supplier, for both green and brown

5 | CONCLUSION AND OUTLOOK

The disappearance of over half the Fortune 500 companies since 2000 due to digitalisation highlights the need for companies who produce LEMs to address this risk. The justification of LEM digitalisation projects has, however, been a roadblock to their implementation. The large investments from both the O&G industry and the large drive industry show that they are
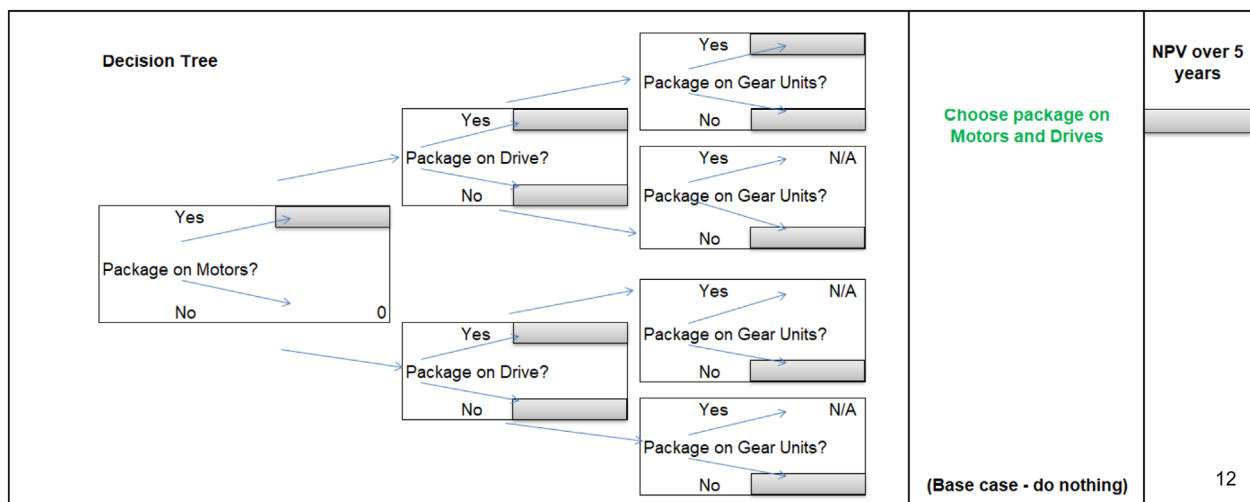

FIGURE 12 Decision tree (Own figure.)

TABLE 4 Key variable sensitivity analysis

aware of the risk of ignoring the digitalisation movement, especially with the challenges of the low oil price in the O&G industry. For this reason, this paper examined a path to find the optimal degree of digitalisation of LEMs to deliver value to both the customer and the supplier.

There are three distinct value cases for the customer: preventative maintenance, improved forecasting, and other digital data value. In the case study, the improved maintenance value stream alone justifies a digitalisation project with a positive NPV. The latter two have the potential to be significant value streams and both require further investigation.

For the supplier, there are three value cases: hardware sales, software sales, and leveraging data value. Whereas hardware sales are the traditional value stream, software analytics and recurring surveillance contracts have justified the digitalisation project from the suppliers' side in the case study.

Risk-based decisions, utilising both customer and supplier data input into a decision tree tool, have shown that there are seven variables with a high or medium impact on the project NPV. Out of these, three variables are required from the customer, which have both a high impact on a digitalisation project NPV and are difficult to obtain: downtime incidents, downtime duration, and deferred time. These should, therefore, be a focus for the customer to reduce the uncertainty. This is especially important for green-field cases due to the lack of historical data and may require a closer collaboration with the supplier and their world-wide fleet data. There are two variables with high impact on the project NPV from the suppliers' side, which are difficult to obtain: reduction in downtime occurrences and avoided downtime. These should be a focus for the supplier as they are significant for both green-field and brown-field projects.

The extent of a digitalisation project can be assessed using the tool created in this work, moving the business case away from the traditional hardware sales to software, analytics, and

data value cases. This has the potential to improve businesses' decisions, increase their revenue streams, and justify a digitalisation project.

The case study using LEMs in the Snøhvit LNG plant returns an NPV value of over 1 million Euro over five years, while including only preventative maintenance value and omitting both improved forecasting and other digital value for simplicity.

Data should be gathered for the key variables to reduce the uncertainty of the digitalisation project. This may require some innovative product offers, such as free installations or reduced OPEX costs for the customer. Further work is also required in the other digitalisation value streams to fully exploit the digital potential. This includes better probabilistic forecasting, better quality gas contract data, and reduced inventory from the customer's side, as well as better hardware and software design and improved analytics from the supplier side. Both the customer and the supplier are also likely to benefit from other digital data value streams, which have yet to be identified.

This paper shows that risk-based decisions can be used to justify projects to digitalise LEMs, which satisfy both the customers' and suppliers' value requirements. This has the potential to revolutionise the old LEM industry by opening significant new value streams and bringing the industry into the digital age.

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