

The Integration of an API619 Screw Compressor Package into the Industrial Internet of Things

W J Milligan^{1,3}, G Poli¹, D K Harrison²

¹ Howden Compressors, Old Govan Road, Renfrew, UK

² Glasgow Caledonian University, Glasgow, UK

³ Author to whom any correspondence should be addressed

billy.milligan@howden.com

Abstract. The Industrial Internet of Things (IIoT) is the industrial subset of the Internet of Things (IoT). IIoT incorporates big data technology, harnessing the instrumentation data, machine to machine communication and automation technologies that have existed in industrial settings for years. As industry in general trends towards the IIoT and as the screw compressor packages developed by Howden Compressors are designed with a minimum design life of 25 years, it is imperative this technology is embedded immediately.

This paper provides the reader with a description on the Industrial Internet of Things before moving onto describing the scope of the problem for an organisation like Howden Compressors who deploy multiple compressor technologies across multiple locations and focuses on the critical measurements particular to high specification screw compressor packages. A brief analysis of how this differs from high volume package manufacturers deploying similar systems is offered. Then follows a description on how the measured information gets from the tip of the instrument in the process pipework or drive train through the different layers, with a description of each layer, into the final presentation layer. The functions available within the presentation layer are taken in turn and the benefits analysed with specific focus on efficiency and availability. The paper concludes with how packagers adopting the IIoT can not only optimise their package but by utilising the machine learning technology and pattern detection applications can adopt completely new business models.

1. The Industrial Internet of Things (IIoT)

The Internet of Things (IoT) refers to connecting devices over the internet allowing them to communicate with humans, applications, and each other. The term Internet of Things was proposed by Kevin Ashton in 1999[1]. The Industrial Internet is a term coined by GE [2] and refers to the integration of complex physical machinery with networked sensors. Therefore the IIoT is the industrial subset of the IoT that is connecting complex physical machinery and their sensors to the internet to allow them to communicate with humans, various applications and each other. The IIoT sees smart machines that can accurately, consistently capture and communicate data.

The convergence of information technology and operations technology (IT/OT), where the industrial automation components are integrated into the business IT infrastructure is being driven by the decision makers within the business. In a recent study by Microsoft [3] only 4% of IoT initiatives were led by IT personnel. This captured data can enable the decision makers within the companies operating screw compressor packages to pick up on inefficiencies and problems sooner thus saving time and money, make better decisions regarding their packages, improve their process and allow the



decision makers within screw compressor manufacturers to develop new business models. However, there are complexities involved in the integration of these two technologies not least the bridging of the old proprietary communications wiring and protocols of the automation world into the more structured and standardized IT world.

The evolution of the compressor control system has seen the change from manual control of motors and valves depending on the operators reading of gauges and sight glasses to rudimentary automatic control systems using relay logic. The advent of programmable logic controllers (PLC) in the 1970's and 1980's allowed the control systems to introduce complex logic into the package control sequence and to communicate with the end users overall factory Supervisory Control And Data Acquisition (SCADA) system or their refinery Distributed Control System (DCS).

Each of the automation houses had developed their own communication protocols and wiring standards such as ControlNet from Rockwell with its co-axial cable or Profibus from Siemens with its twisted pair cable, with only a few becoming adopted industry wide such as Foundation Fieldbus via the FieldComm Group or DeviceNet with the development of the Open DeviceNet Vendors Association. These propriety protocols, often referred to as industrial fieldbuses, were most commonly deployed between individual nodes of a small control system for example between a PLC processor rack and racks of inputs and outputs (IO) that was being controlled by the processor or perhaps between the PLC and a piece of smart plant such as a control valve. Rather than run multiple cables for limit switches, positioners and solenoids a single cable could carry the communication data to and from the valve. Historically the communication between the package PLC and the SCADA or DCS would have been a serial connection communicating at a few thousand bits per second baud rate such as an RS485 Modbus connection. Overtime the RS232, RS422 and RS485 SCADA and DCS connections have been phased out to be replaced with more robust Ethernet connections. More specifically 100Base-Tx Ethernet accounts for about 95% of all Ethernet data transfers [4] and has changed the automation industry with this also now replacing the industrial fieldbuses. The automation houses have realized the advantages of connectivity to the IT infrastructure and have developed Ethernet communications modules that fit into the PLC chassis alongside the IO modules to bridge between the control system proprietary protocols and the IT network. This is the starting point of the OT/IT convergence and has been taking place over the past decade. The IIoT is a further evolution of this convergence with the adopted IT standard working practices being used to present this data to the business decision makers.

2. The API619 Screw Compressor Package

Howden Compressors and complete compressor packages are used in the petroleum, petrochemical, refrigeration, oil and gas, power generation and other markets where performance and reliability are critical. Applications of compressors can include sour gas processing, flare gas recovery, gas reliquification and fuel gas boosting for turbines. Howden designs and manufactures a range of different compressor packages that can be categorised as: screw compressors, reciprocating piston compressors, diaphragm compressors and turbo compressors.

The selection of a reciprocating-, centrifugal, turbo, or screw compressor is based on the flow and pressure requirements that are specified by the client. In overlap areas of the operating envelope the selection of a particular type of compressor is not explicit. In these cases the selection is based on other technical and commercial aspects.

During the detailed design of these packages hazard and operability studies (HAZOP) and Safety Integrity Level (SIL) assessments are held as the severity of an accident if something did go wrong could lead to serious injury or death to one or more people, have a sizable environmental impact and cost hundreds of thousands if not millions of pounds to repair.

3. High Volume Screw Compressor Packages

Remote monitoring has been tried on a single node API 619 screw compressor package deployed in the field by Kobelco EDTI Compressors Inc previously. The application was for five Kobelco KS31 SHE compressors feeding fuel gas into four GE 7FA gas turbines. One of the compressor packages was a spare standby. This was a single site that, if required, an engineer could dial into the system to watch it live or it could be setup to email a supervisor if a particular alarm occurred.

More commonly, remote monitoring has also been rolled out on large scale manufactured machines of the same design. Gardner Denver has developed the ESP 20/20 compressor monitoring system for their air compressors. Ingersoll Rand has developed the IntelliGuard system to do the same and Atlas-Copco has iAccess. It is important to understand these are off the shelf, high volume manufactured, air compressor systems that these companies manufacture. Rolls-Royce have deployed a similar system to remotely monitor engine health albeit on a much larger scale in terms of points measured: air compressor manufacturers measure between five and fifteen whereas Rolls-Royce measure twenty-five. If this is compared with a two stage oil free package currently being manufactured in Renfrew that has one hundred and seventy different measurements being measured at any one time and the next package may be a relatively low spec oil injected machine with thirty measurement points on it. It can be seen that the API619 screw compressor package monitoring system needs to have orders of magnitude amounts of points available from an off the shelf compressor package monitoring system and at the same time also be more dynamic in the ability to chose what points are being measured whereas these companies manufacturing large volumes of compressors, all of the same technology, and all of the same design they only need to design the monitoring system once but roll it out many times and always looking at the same performance data.

The engine health management system from Rolls-Royce should also be considered in terms of criticality: Gardner Denver, Ingersoll Rand and Atlas-Copco manufacture air compressors for industrial processes where failure may well cause loss of production if the compressors cannot be brought back online by the time the reservoir empties whereas the Rolls-Royce system is monitoring aeroplane engines operating at thirty thousand feet with up to hundreds of lives on board. The model developed for critical compressor packages would tend towards the engine systems model rather than the industrial compressor model due to the number of IO and critical nature of the machines.

4. The Data Journey

The figure below is a graphical representation of the data journey from the point of measurement through the various layers to the business presentation layer. On a typical package the start of this process is at a compressor or motor bearing or a gas pressure or oil temperature. From here the instrument is connected via a junction box located at the edge of the package to the package control system. These instruments are then grouped together and run back to the PLC on larger multi-core cables to the PLC in a control room. Although the above describes a typical package there can be many different adaptations of the sensors and control system layer with control panels sometimes being mounted on the package rather than in a blast proof control room a few hundred meters away. Or to save copper cabling costs sometimes the multicore home run cables are replaced with fiber optical cable for the non critical signals and the IO is moved to the package junction boxes.

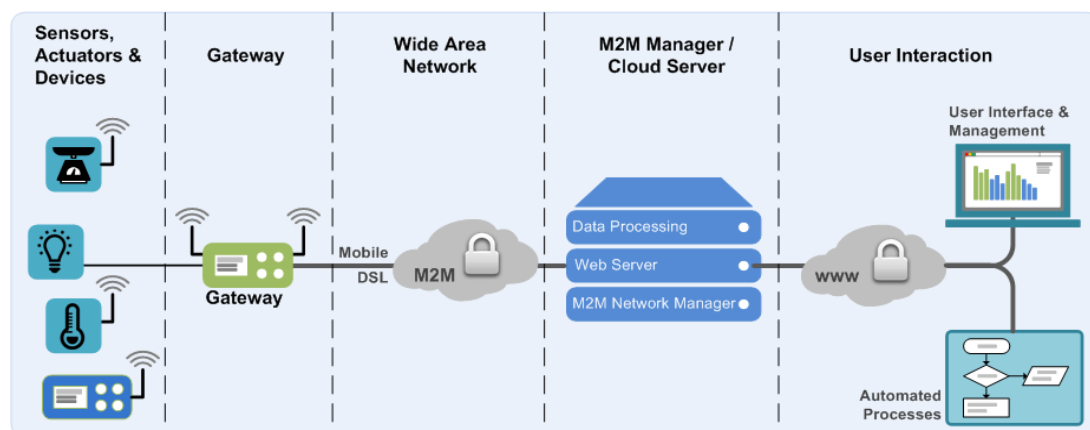


Figure 1, The data journey from the sensing point to business presentation level.

The PLC then meets the Edge. This is the gateway between the OP and the IT worlds or the control system local area network (LAN) and the wide area network (WAN). The data then makes its way into a database that will be hosted either in an on-premises server, in the cloud or a combination of both. The combination or hybrid scenario comes about when sensitive business data cannot be entrusted to third parties but the non-critical non-sensitive data can be stored on external sources. Microsoft Azure and Amazon Web Services are example of cloud based services that IIoT applications are being hosted on. Indeed Rockwell Automation has partnered with Microsoft and are using Azure in their services business and are working together and aligning strategically around technology roadmaps allowing easily development and deployment of IIoT applications using their respective products.

Lastly is the presentation layer where the business decision makers can see and interrogate it. This layer used to be a SCADA system or a DCS where the operators could view the data supplied by the PLC and make decisions based on it. This would all be done in a control room local to the PLC and local to the process. The evolution into the IIoT means this can be the general plant manager at breakfast before coming to work in the morning on his phone or, more importantly for a screw compressor manufacturer, it could be the engineering department interrogating historical data on a particular bearing on a particular size of machine. The different platforms available for the presentation layer all have the ability to drill down into specific areas with, for instance, the ability to trend over a two year period all of the inlet end male rotor bearing temperatures of a particular model of compressor with a few button clicks so see if there is any correlations to be made.

5. Proof of Concept

At the moment an initial single node proof of concept has been developed. The first step in the development of the system was to create a test assembly that was able to simulate the functionality of an operational screw compressor package. This was achieved by using an Allen Bradley ControlLogix L61 PLC which has 16 analogue inputs, 8 analogue outputs, 16 digital outputs and 16 digital inputs that are all used to control and monitor the operation of the simulated screw compressor. The inputs and outputs to the PLC were simulated via an array of variable resistors, I/O switches, LEDs and ammeters which were situated within a separate control panel. To monitor the real time simulated analogue and digital inputs and outputs of the PLC a Human Machine Interface (HMI) was added to the test assembly just as it would have if it were a real package. Screenshots of the HMI program used to monitor the PLC can be seen in the figure below.

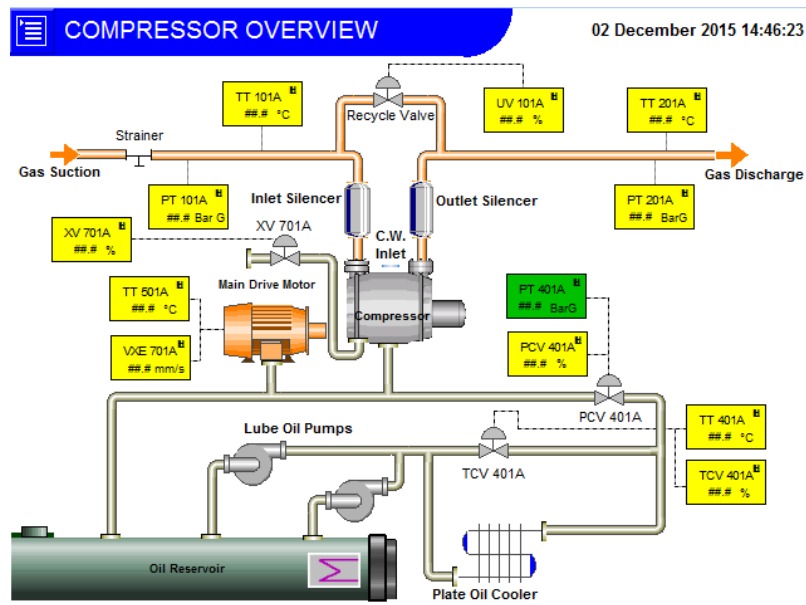


Figure 2, Proof of concept HMI screen.

To add a business presentation layer and data storage functionality to the proof of concept assembly, new software and hardware components were added. After researching available software options it was concluded that FactoryTalk Historian SE [5] would be the most suitable solution to store the historical data from the test assembly as it could easily integrate with the installed Allen Bradley PLC. This software is able to capture process data from the PLC which could be programmed to capture an extensive archive of data that could be used to assess any PLC input or output over a chosen period of time. The FactoryTalk Historian software was installed on a server running Windows Server 2008 R2 which was connected to the PLC via Ethernet TCP/IP that made it possible for the software to collect and store data on any of the inputs and outputs defined in the PLC ladder logic. FactoryTalk Historian can connect to not only Allen-Bradley PLCs but using any 3rd part PLC or data acquisition (DAQ) device by means of an object linking and embedding for process control (OPC) connection. Just another example of the OT/IT convergence but it does allow almost any industrial automation device to put data into the database.

To add analytical functionality to the test assembly FactoryTalk VantagePoint software was added to the server PC. This software expanded the capability of the historian server by allowing anyone that was connected to the server PC to log in to a page on their internet browser via a web address and access the historical data stored by the FactoryTalk Historian software [6]. This software is also capable of producing predetermined reports that can be customised to present data on components that may be deemed the most likely to fail on the compressor. This would give engineers the ability to quickly assess the operational health of any chosen component on the compressor simply by logging into a PC that is connected to the server PC.

To make this test truly represent a screw compressor package installed in a remote location, a mobile GSM modem was integrated into the test assembly via an Ethernet connection. The GSM modem allows for an engineer to connect to the PLC and the condition monitoring system, regardless of their location, allowing them to then carry out data analysis on the industrial machine. It is beneficial to include a remote monitoring system as it allows for the time taken for a system fault to be diagnosed to be minimised, reduces the expenditure on engineers being called out to assess machine faults and reduces the resulting downtime caused by a component failure [7]. The completed machine monitoring test assembly is shown in Figure 3.



Figure 3, the single node proof of concept test assembly.

6. Presentation Layer

The presentation layer of any IIoT platform must be able to perform a variety of roles as this will be used by various levels throughout a business. This layer is responsible for being able to extract the data into well known platforms like Microsoft Excel, SQL Server Reporting and SharePoint to allow the data to be published in business reports and presentation. These reports, trends and dashboards should be able to be pre-configured to save time every time the report is issued. Mobile functionality is also required to allow not just local intranet but web-enabled browsing, with end users being able to create ad-hoc displays to interrogate data and create reports on their device. The presentation layer must have the functionality to provide information in a timely manner, via SMS or email for instance, to allow the business decision makers time to make productive decisions.

The presentation layer must be able to securely link to a variety of databases such as the hybrid on-premises storage databases and cloud storage databases scenario discussed earlier. The platform must also securely allow users only see information only pertaining to them by defining user roles.

Most importantly the presentation layer, and also the data storage solution, must be scalable. This is one of the advantages of the cloud solutions over the on-premises hardware solution. The faceplate template model of the screw compressor package that links to the data must be able to be repeated over and over every time a new package is deployed to the field. Once the initial faceplate template is developed, the Historian server is pointed at the PLC in the field and the standard template is then copied and re-named and is pointed to the tags in the Historian server. This facilitates quick introduction of any new package into the system but requires the PLC programme to have a standard structure of PLC tags so the suction pressure value is always stored in the same tag in every machine same with the discharge pressure etc etc. Figure 4 below demonstrate the data capturing capabilities that are available by using both FactoryTalk Historian and FactoryTalk VantagePoint together in the proof of concept test.

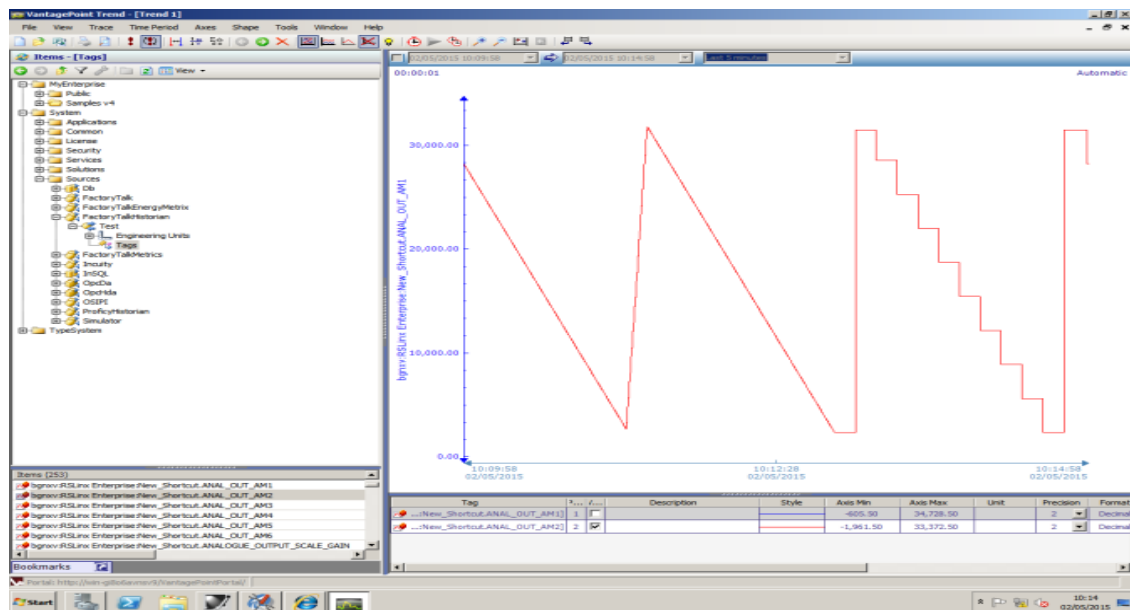


Figure 4, simulated historical data displayed on the presentation software during test.

Many IIoT platforms are introducing augmented reality features that offer exciting possibilities. They propose that a service engineer turns up at a package, opens their phone, points it at the package and a 3-D model of the package appears on the display, they can bring up all the relevant drawings, they can dismantle the 3-D model and see how to get to a particular component and see all of the process values (pressure, temperatures, flows and vibrations etc) superimposed on the model. These are however still in their infancy but small examples of pumps and motorbikes have been produced.

7. Conclusions and Future Work

The proof of concept single node revealed that the technology is available to gather the information right at the front end of a compressor package and make it available at any time to all levels of the business. The hardware installed in automation systems deployed just now already integrate easily with the business IT infrastructure. Even older isolated packages with obscure protocols could be integrated albeit with some design work required. The bespoke and critical nature of these packages means that the model developed by the high volume screw compressor manufacturers would be the wrong model to adopt. The IO count needs to be increased by an order of magnitude and the template for the packages needs to be more dynamic than that model. With this in mind two networked proof of concepts are in the advanced stages of development.

One is a Rockwell Automation platform similar to the single node proof of concept but this time rather than using single server with all of the historian software and presentation and analytic software installed on the one machine the historian software is installed on one server and the presentation and analytic software on a separate server. The flight desk is still used to feed simulated data into the PLC and HMI assembly. The Rockwell networked proof of concept architecture is shown below in Figure 5 with the only difference between the proof of concept and a finalised platform would be that rather than hosting on Howden servers these would be copied and migrated into the Microsoft Azure cloud.

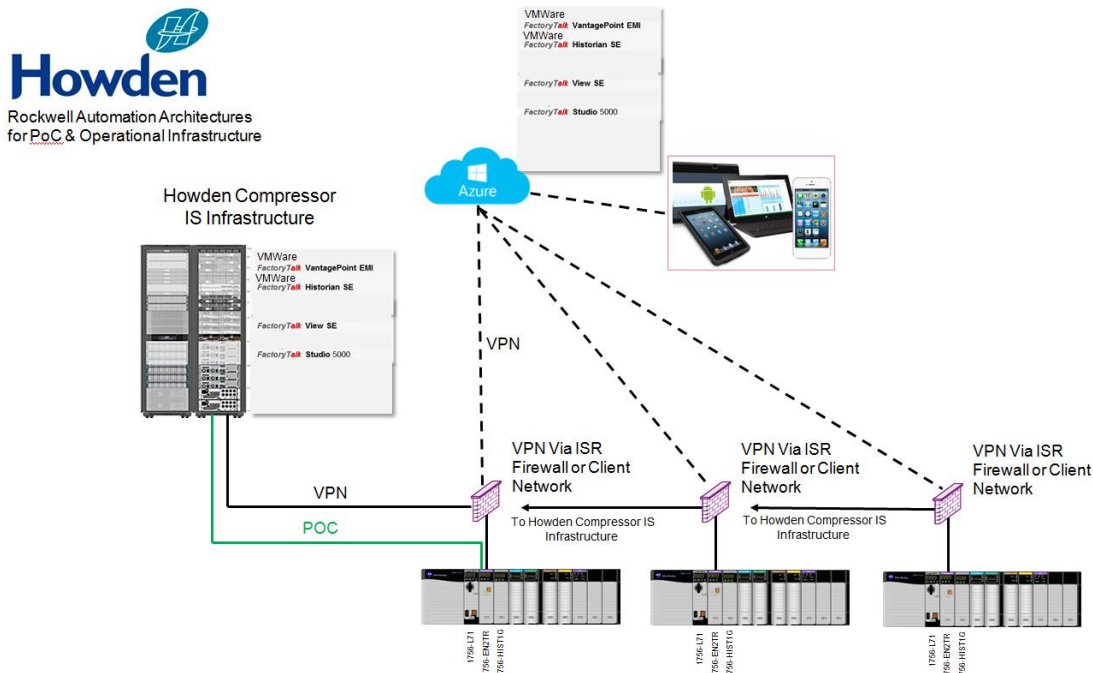


Figure 5, the Rockwell IIoT network proof of concept (courtesy of Rockwell Automation).

The second platform is ThingWorx from PTC deployed by InVMA. It provides IoT specific development tools and capabilities that enable developers to rapidly build and deploy smart, connected solutions for the Internet of Things. ThingWorx is purpose-built for the development of scalable and secure solutions that are simple to create and makes end-user experiences more compelling.

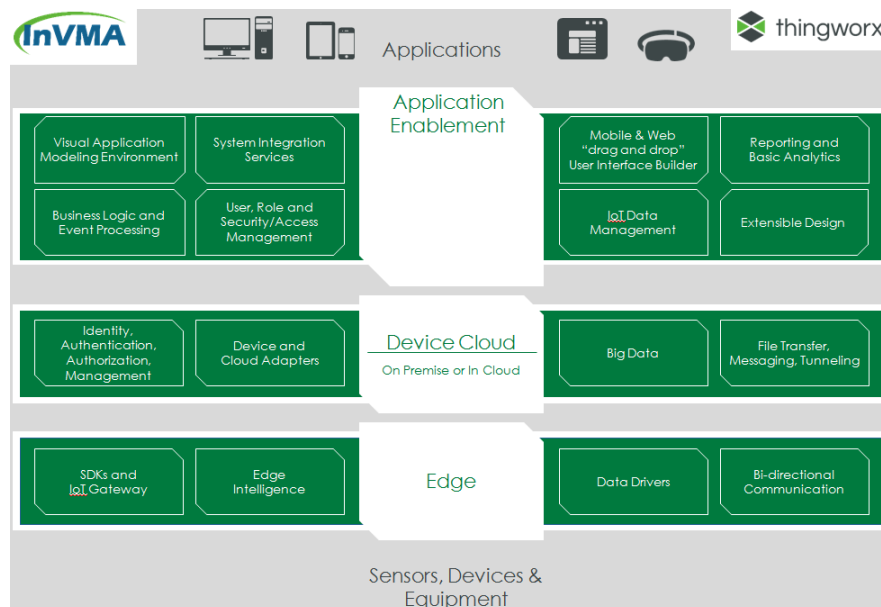


Figure 6, the PTC Thingworx proof of concept in development by InVMA (courtesy of InVMA).

A powerful feature of the ThingWorx capability is its Analytics add-on. Analytics enables developers to quickly and easily add real-time pattern and anomaly detection and predictive analytics to the platforms they build so rather than wait for the platform to tell the end user that the compressor

has a high bearing temperature this add-on mines the data and recognizes that the last time this bearing started to trend like this a high temperature alarm was raised in approximately three weeks time and notifies the user prior to the machine going into alarm. Analytics is designed to be used by end users that may not have expertise in complex mathematics, statistics or machine learning with the alternative is manual coding of maintenance of predictive models and recommendations. This requires specific expertise in advanced analytics, statistical modeling, machine learning and system integration.

Both of these platforms offer significant advantages and after the final development and trial period a business case for both will be presented to the Howden Compressors senior management team but it should be noted that the dynamic nature and scalability of these platforms make them ideal not only for the screw compressor business but for capturing the data for all of the air and gas handling equipment manufactured within the group.

The development and implementation of the IIoT platform will transform the compressor packaging industry on three different levels. Operationally the platform will be used to optimise performance of the packages and reduce service costs all for the end users thanks to examples like the production managers and maintenance managers being able to access and interrogate process and machine condition data. Strategically the platform will elevate the manufacturer's relationship with its end users as not only an innovator but also something that will differentiate the manufacturer from their competitors, at least for the time being. Lastly the IIoT platform, if implemented correctly, allows completely different business models to be developed: for instance no longer will an end user pay \$2M USD for a compressor package but they will hire it at \$8K USD a week so long as the manufacturer guarantees 99% availability with the IIoT platform being used to monitor the health of the package.

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