ADAPTATION OF REMOTE AND AUTONOMOUS OPERATION (RAO) FOR ROTATING EQUIPMENT OF PETRONAS FACILITIES

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ABSTRACT

The Oil and Gas industry is increasingly facing with more complex and hazardous operations. This is resultant from integration with a more complex feed and product properties as well as requirement for operation in harsher environment. At the same time, a much stronger Environmental regulation is currently enforced which demands strict adherence and compliance by all Operating Assets/Facilities.

At the same time, technology has caught up rapidly in the last few years. More industries have started to embrace automation as a safety and productivity enabler and as a critical factor in running business and operation. The center of attention to this shift is automation of Rotating Equipment covering broad range from Turbomachinery down until a Potable Water Pump.

Network communication enhancement via 5G technology has allowed remote operations and control technology able to be safely deployed. The new norm of Remote and Autonomous Operation (RAO) via Artificial Intelligence, Machine Learning, Digitalization effort as well as Digital Twins are also increasingly being adopted to allow for better performance monitoring, remote trouble shooting, predictive and prescriptive ability for Rotating Equipment.

As proven in many industries and sector, PETRONAS have also successfully embarked on remote and autonomous operation journey for its Rotating Equipment fleet which will add clear value: it can improve safety, increase production efficiency, and lower maintenance costs. Although, implementing autonomous systems may also expose and presents new challenges such as cyber security and safety risks, the obvious advantage supersedes the risk which needs to be managed accordingly. This paper explains the challenges, the lesson learnt and PETRONAS approach in adapting RAO for Rotating Equipment.

INTRODUCTION

Remote Operation by definition means operating an equipment, a facility or even an assembly line from separate location and not physically presence at the same location of the subject. Autonomous however means an independent, self-governing, self-sufficient system which are able to make free and independent decisions. RAO is then, a concept coined to indicate an equipment or a system that can be operated independently with minimum control from remote location. Although the concept is proven in other applications such as military, aviation and in smart factory, the same vision for oil and gas production facilities has been a concept discussed for a number of years. There are unique challenges to different industry when it comes to implementing the RAO but the benefit is far more attractive than those challenges which is why the industries are shifting its course. Among the main reason industry is shifting towards remote and autonomous operations is the obvious improvement in productivity, efficiency, Health Safety Environment (HSE), Capital Expenditure (CAPEX) and Operating Expenditure (OPEX).

Recent pandemic has accelerated the needs for oil and gas facilities to have remote and autonomous operations where constant evolving threats and uncertainty of quarantine, Covid19 workplace clusters, travel restrictions internationally as well as locally have restricted people movement that at one point of time, it was almost impossible to attend to an operational need within the stipulated response time.

For oil and gas specific, the locations are getting deeper, harsher and remotely located which leads to challenging design and expensive development and operational cost. Coupled with that, the resources at these locations are getting more and more complex with elements that are harder to handle such as Hydrogen Sulfide (H_2S), Mercury, Carbon Dioxide (CO_2), sandy and emulsified liquid. These condition not only bring challenges in design but pose a great HSE risk to operating personnel. Making thing worse was the pandemic situation which literally disrupt the supply chain, changing immediately the supply and demand scene from producers' market to consumers' market with oil trading at negative value in April 2020. These rapid fluctuation in global economy not only disrupt the supply chain, rather it brings operational disruption and in order to stay competitive, adaptation to these fluctuation needs to happen fast. RAO among others brings about the promise for fast response and subsequently adjusting to these fluctuation in timely manner as compared to manual intervention.

MAKING LOW MANNED BROWNFIELD INSTALLATIONS A REALITY

One of the approaches for de-manning brownfield production installation in offshore location is via value driven and not purely based on technology oriented alone. The concept is to hinge on Return on Investment, prioritizing investment which will enable low-manned operation in a small step towards fully unmanned operations. Elgonda *et. al* (2021) stated that there are 6 elements involves for an all-inclusive conversion includes:

i. Unified data management
ii. Change management

iii. Remote collaboration
iv. Remotely controlled production operations
v. Predictive analytics to reduce unplanned downtime
vi. Automated inspections

It is also stated that although full autonomy is not yet attainable, but low manned and normally unmanned operations as a stepping stone to autonomy is indeed feasible. This is true as the oil and gas facilities and its operations are strictly governed by international codes and practices such as American Petroleum Institute (API) codes and Recommended Practices (RP) that it become challenging to maneuver the operation and practices into full autonomous instantly. Rather it requires small and persistence method such as low manned or normally unmanned operations before full autonomous is attainable in oil and gas industry. This shouldn't be misunderstood as the codes are discouraging the remote operations, rather these codes and practices are there as a result of valuable industrial safety lesson learnt and best practices to ensure the industry remains safe yet profitable. Hence, small and continuous steps towards full autonomy will ensure the end goal doesn't change yet at the same time allowing the industry to maneuver towards the end goal safely.

Elgonda *et.al* (2021) also highlighted that, when full autonomous are coined for this industry, all operators and engineering contractors starts to focus their effort to unman the new built or greenfield projects rather than challenging brownfield existing platforms. This is because for greenfield projects, design decisions to support unmanned operation can be made upfront with a justifiable economics of 25 years or more design life, but for a brownfield assets, things become a little complicated as it involves retrofitting and re-engineering for a limited remaining life of the assets which makes the low-unmanned brownfields indeed an uphill task. This however is feasible if the execution are carried out with ROI concepts focusing on strategic approach for Rotating Equipment, Electrical and Automation Systems.

The first steps to achieve low manned or unmanned operation is to define the "level of low" for a staggered achievement of unmanned eventually. These can be different from an operator to another operator or even from one facility to another facility within the same operating company. The next steps would be to assess the assets and define its "as-is" state before aiming to reduce the frequency of maintenance and subsequently the manning level but keeping in mind to maintain production up time. Elgonda *et. al* (2021), also state the prime benefits for low manned facility are:

i. Lower OPEX
ii. Improved Safety
iii. Increased Uptime
iv. Reduce Carbon Emission and environmental Impact.

On the other hand, enablers of de-manning are cybersecurity, data hub and lastly the change management of transforming people, processes, and organization. Combining all these will drive a successful implementation of de-manning a brownfield facility.

LOW MANNED PRODUCTION INSTALLATION: CONSIDERATION FOR ROTATING EQUIPMENT, ELECTRICAL & AUTOMATION SYSTEMS AND DIGITALIZATION

Technology barriers have historically limited the oil and gas industry effort to unmanned the oil fields operations. Recent change in the technology sector have now bring about the hope to push thru the idea of un-manning the oil fields in order to improve the sustainability and to lower the operating cost in order to remain profitable in this challenging market. Connectivity and digitalization advancement have made it possible to monitor and operate large complex remotely, safely and cost effectively. The benefit promised to be reaped are Lower OPEX, improved safety, higher uptime and lower emission. For a greenfield installation, there have been a number of examples of successful un-manning or low manned operation, but for a brownfield, there are huge skepticism on the ability to convert these old assets to low manned or even an unmanned operation. Main reason for this is that for a greenfield installation, decisions can be made upfront as early as during a concept selection, hence the subsequent design are accordingly for minimum manpower or unmanned operations. Among the characteristic for such design are high reliability and highly digitalized equipment/installations from the very beginning making it easier for operators to realize financial return from low-manned greenfield installation over the facility life of 25-30 years as described by Elgonda (2021).

This however is not the same for brownfield installation where for brownfield, the concept is rather on modification, retrofitting and old system to a new digitalized system which sometimes tends to be costlier and difficult to justify its economics in a much shorter remaining life span of the field. Nevertheless, as per Elgonda (2021), with a strategic approach built around digitalization and a particular focus on rotating equipment, electrical and automation systems, de-manning can deliver profitable return even on aging fields. Adding on to that is the considerations in creating low-manned production facility lies on the following basis regardless whether it is a greenfield or brownfield:

1. Cybersecure Connectivity – High bandwidth, Low Latency
2. Digitalization – Building virtual capability thru predictive analytics, connected workers and automated inspections

3. Automation – Taking people off the site and cutting of the loop by having remote control, package control in ICSS, high quality data acquisition and automation of operational sequences
4. Equipment – Designed for unmanned operations with consideration for less planned and unplanned maintenance and no routine task

The use case for Aeroderivative Gas Turbine Packages – automating routine activities; indicates the efforts put forward to optimize the man hours by extending intervals between routine inspections and maintenance intervals. The approach adopted started with OEM manual validation and updating of the manual after review. Some of the varying frequency tasked were maintained while others were clustered into one to extend the intervals. The options then lies between few months' interval extension to even 1 year extension depending on the hardware and software modification and upgrades with ample sets of operating data available as part of statistical analysis.
Cases illustrated among them was, one of the platforms in the North Sea was able to achieve $7/barrel production cost with low manning concept and is in operation since 2016. There are several other low-manned facilities quoted such as FPSO western of Australia with targeted manning of only 12pax suitable for one helicopter transit, new platform in North Sea with a target of 50% reduction in OPEX, 30% reduction in CAPEX and 90% reduction in safety incident by adopting low manning, and another FPSO operator targeting in staggered from 130 PoB to < 50 PoB by 2025 and fully unmanned by 2030.

Above and beyond the direct saving of manpower and manhours, there are other benefits when digitalization and automation are implemented such as; reduction in consumables cost, saving on ICSS and PLC spares holdings by having a common integrated control, reduction of unplanned shutdown with early warning systems and fewer technical experts mobilization with the implementation of digital twins, AR/VR, connected workers and most importantly is the improved safety. Study by Cox (2016) indicates that human factors contribute to 80% of offshore incidents, hence de-manning not only increase safety by limiting fewer people in hazardous area and application, but also increase the safety of facilities by taking human out of the incident loop.

REMOTE AUTONOMOUS OPERATION (RAO) ADAPTATION FOR ROTATING EQUIPMENT FOR PETRONAS

In March 2020, when nationwide movement control order or lockdown was announced as part of an effort to address the pandemic, PETRONAS was not spared, where due to that, immediately there was a disruption to workforce movement and hence the workflow. Adding to already a difficult situation, in April 2020, when oil price traded negative, PETRONAS felt the pinch as well from this unprecedented market incident. Immediately tank terminals were reporting "tank top" incidents in what was said to be the biggest disruption in supply and demand. These were just an add-up to an already challenging situation such as harsh and remote location of oil and gas reserves, stronger environmental regulation, complex plant feed containing H_2S, CO_2, Mercury and sands.

Harsher, remote, deeper, and smaller reserve have challenging economic models which requires higher CAPEX for its development. The same goes for a complex sour feed where elements like H_2S, Mercury and wet CO_2 will lead to requirement of special material or additional sophisticated treatment systems which not only means higher CAPEX but pose an immediate safety risk as hazardous area operation. The more sophisticated a processing train are, the higher is the potential for trips or incidents due to human error. While facing the unprecedented challenges, the OPEX cost however remains unchanged despite a drop in oil price from $100/barrel to lesser than $40/barrel which just add on to the bleedings of the coffer. As the saying goes, "*you have to do things differently to get a different result"*, PETRONAS strategically pivoted on remote and autonomous operations with a target to reduce CAPEX, OPEX and HSE exposure while increasing the productivity, efficiency, and compliance to environmental regulation.

Technological advancement such as 5G communication network, industrial drones, Unmanned Aerial Vehicle (UAV), Unmanned Ground Vehicle (UGV), smart wearables including Augmented Reality (AR)/Virtual Reality (VR) has opened up new ways of working and coupled that with Artificial Intelligence and Machine Learning for better predictive and prescriptive analytics has indeed accelerated the pace of adaptation for RAO. While adaptation of RAO across PETRONAS is a topic on its own, this paper will zoom into discussion specifically for the adaptation of RAO for rotating equipment.

Adaptation of RAO for rotating equipment depends very much on the overall autonomy level for the intended field/production facilities. These production facilities autonomy level as well as overall adaptation across PETRONAS is started with a first step of having a PETRONAS Technical Guidelines (PTG) to assist the change process and most importantly aligning the implementation across the group. This is a very important step in ensuring standardization of definition and details of implementation, that when a field is adopting certain RAO level, it has to be defined in accordance with a central reference system which will then ensure that another platform or facilities at different location which intend to achieve same level of automation, do have a same definition and deployment of technology to achieve same objective as per the definitions. Hence the establishment of a PTG will help to guide and oversee these standardizations.

Below figure depict the RAO level established to mark and serve as guidelines in implementation which is based on two dimensions that are; Scope of automated task and role of a human. It begins with no autonomy with humans heavily involved (Level 0) and rises to full autonomy with no human involvement (Level 5). These levels are guided by the Level of Maturity definition as per International Federation of Automatic Control (IFAC, 2019) and The Autonomous Industrial Plant (*ClassNK, Guidelines For Automated / Autonomous Operation on Ships (ver. 1.0). 2020.*).

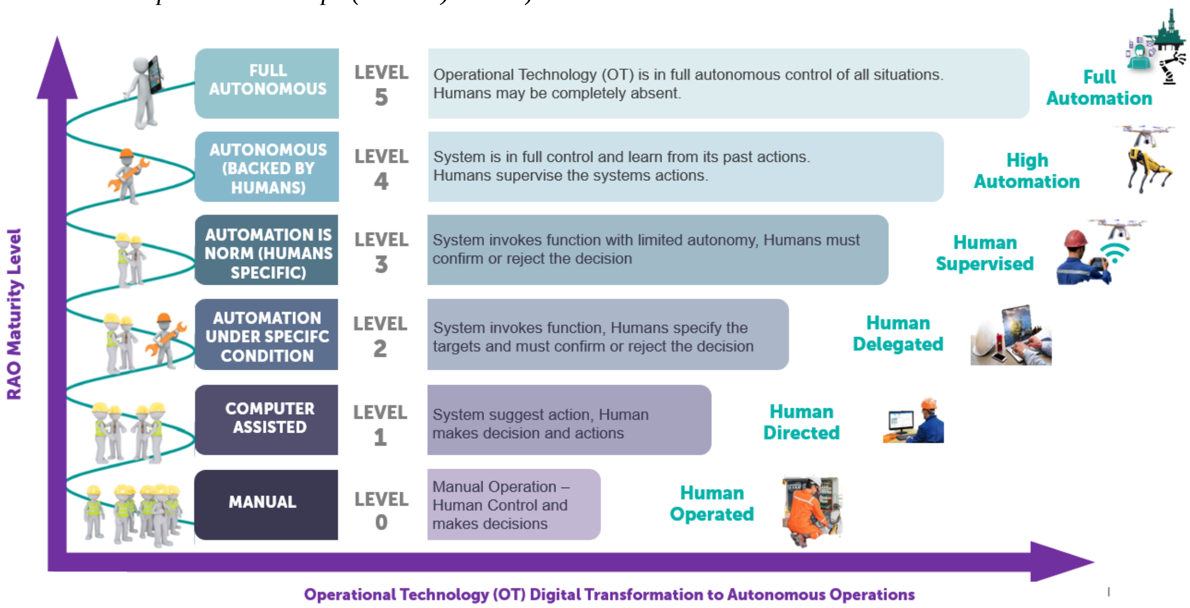


Figure 1: RAO Maturity Level

For each of the level, it is also of utmost important to define the degree of automation as well, which means the decision making (authority) deferred from the human to the system. It should make a distinction between the role of human and the role of the system among various function. These functions are based on the concept of how the human process a certain information which are summarized as below:

i. Information Acquisition
ii. Information and situational Analysis
iii. Decision & Action selection
iv. Action implementation

As per Bureau Veritas, Guidelines for Autonomous Shipping (2019), these degrees of automation are defined as per figure below:

Degree of Automation		Manned	Definition	Information Acquisition	Information Analysis	Decision & Action Selection	Action Implementation
0	Human Operated	Yes	▪ Automated or manual operations are under human control. ▪ Human makes all decisions and controls all functions.	System / Human	Human	Human	Human
1	Human Directed	Yes	▪ Decision support: system suggests actions. ▪ Human makes decisions and actions.	System	System / Human	Human	Human
2	Human Delegated	Yes/No	▪ System invokes functions. ▪ Human must confirm decisions. ▪ Human can reject decisions.	System	System	Human	System
3	Human Supervised	Yes/No	▪ System invokes functions and may receive human reaction / permission / confirmation. ▪ Human is always informed of the decisions / actions and can intervene at any time and give permission to operate.	System/ Human	System / Human	System / Human	System / Human
4	High Automation	Yes/No	▪ System invokes functions without waiting for human reaction. ▪ System is not expecting confirmation. ▪ Human is always informed of the decisions and actions.	Advanced System	Advanced System	Advanced System / Human	Advanced System
5	Full Automation	Yes/No	▪ System invokes functions without informing the human, except in case of emergency. ▪ System is not expecting confirmation. ▪ Human is informed only in case of emergency	Advanced System	Advanced System	Advanced System	Advanced System

Figure 2: Degree of Automation

The field / processing facilities autonomy levels are establish based on a business case for that specific facilities which are unique to each individual facility. As such, whether it is a greenfield new development project or a brownfield conversion from manned facilities to unmanned remote operation or even to a fully autonomous operation, the fundamental to these changes are its business case and return on investment. Among other things that goes into the economics to justify the targeted level of remote and autonomous operations are the following elements:

i. CAPEX savings thru bedding reduction in the case of greenfield projects
ii. CAPEX reduction by eliminating LQ for offshore
iii. OPEX savings thru low manned option, unmanned short visit interval (1 visit in 2 weeks), medium visit interval (1 visit in a month) or long visit interval (1 visit in 3 months/6months).
iv. OPEX savings thru lesser helicopter, supply vessels, trucks, food, medical supplies and medevac requirements
v. OPEX savings thru reduced frequency or prolonged maintenance interval of equipment (AI assisted predictive and prescriptive maintenance strategy)
vi. OPEX savings from consolidation of maintenance works (volume vs cost)
vii. Savings from production deferment
viii. CAPEX and OPEX for implementation of RAO level

As greenfield projects are crafting things from scratch, it is relatively easier to set the intended RAO level and economically justify the autonomy level for the intended design life of 20 – 30 years. It is also easier for its requirement to be embedded from as early as conceptual design phase and follow thru the execution up until Engineering Procurement Construction Commissioning (EPCC) stage. However, things are not the same for brownfield facilities. It is always a challenge to establish the intended RAO level and justify it economically for the remaining life of sometimes less than 10 years. Justifying the intended RAO level has to be done after the cost of implementation/modification is established and to establish such cost, it requires a clear technical requirement or gap analysis from the "as-is" state to the "to-be" state. But the "to-be" state is yet to be clear because of the unclear economics earlier on, making it a catch-22 case. Hence for a brownfield facility, it is always best to establish few options of targeted RAO level and worked out on the exit lane from there.

As the field / facilities intended RAO level or the options of targeted RAO level is attained, adaptation of rotating equipment will follow suit to support the overall RAO level. The first step is to establish the "as-is" basis which is establish through the Asset Readiness Assessment (ARA) study. The ARA exercise covers every aspect of a rotating equipment from the operation such as start, stop and running, EBC, CBM up to scheduled maintenance / shutdown. It is also part of the exercise to establish the level of data available for the unit which is termed as Rotating Data Architecture (RDA). As such, it is important that the correct participant and stake holders are present during these assessments. As the degree of automation is about establishing how much of a human function are deferred to the system, it is then very important to establish what are the level of data available to support these deferments. When a human is taken out of the plant day to day operation, the senses of a human needs to be replaced with equivalent data which is defined as Information Acquisition Process in the human information processing model. These data then will support the Remote Operation Centre (ROC) and Remote Engineering Centre (REC) to establish the condition of a remotely operated rotating equipment and make relevant day to day judgement on its operation. Hence during the rotating equipment assessment, it is important to establish the "as-is" level of data available which will then provide the gap and subsequently the sensors required to complement the data to support the intended RAO level. Some of the important RDA assessed are:

1. Status:
    i. On/Off/Standby/Remote/Local
    ii. Physical (noise, leaking, housekeeping)
    iii. Start-up (Crank motor available, Successful Pre-lube, Successful roll, etc)

2. Main Process
    i. Flow
    ii. Suction & discharge pressure
    iii. Suction & discharge temperature
    iv. Filters dP
    v. Anti-Surge valve position (for related application)

3. Lube Oil
    i. Lube oil tank level
    ii. Rundown tank level
    iii. Supply pressure & temperature
    iv. Filter dP

4. Condition Monitoring
    i. Speed
    ii. Vibration DE & NDE (X,Y,Z)
    iii. DE& NDE bearing temperature

The completion of RDA requires that in the “as-is” state, each of these data, are defined on its path as to how it is being captured and where are the signals currently being sent to. As an example, whether these data are currently being collected manually or there is a mechanism to acquire the data automatically. The subsequent exercise would be to establish where is these data residing, whether in a PI system, DCS system or any other means to store it. Once completed, this gave an overall view of the RDA for each unique platform design. Likewise, EBC and CBM activities are assessed as well to establish what are the activities currently assigned for each tag number and how it is performed. These activities will need to be assessed for its automation capability and ability to support the intended RAO level.
Completion of the ARA exercise will provide an overview of the rotating equipment capability in terms of “as-is" condition covering the remote monitoring and remote control capability, and the ability or gap for the equipment to be upgraded to achieve the targeted RAO level. Figure below provide an example of results from ARA study. Part of the summary from ARA assessment will also recommend the proposed RAO level for that equipment based on the outcome of the study which might or might not be the same as the intended / targeted RAO level. This will provide a means to resolve the catch-22 issue earlier on and provide a clear direction for subsequent exercise, the economic assessment to proceed accordingly.

Platform A					Operation				Maintenance			As Is RAO Level	Proposed RAO Level
					Remote Monitoring	Remote Control							
Item	Service	Tag Number	Equipment Type	Driver		Start Up	Running	Shutdown USD/ESD	EBC	PPM/CBM	Schedule Maintenance		
1	Gas Compressor	Comp 1	Cent. Compressor	Gas Turbine	Yes (Op. Parameters)	L0	L1	L1	L0	L0/L1	L0	L1	L2
2	Condensate Export Pump	Pump 1	Centrifugal Pump	Electric Motor	Yes (Op. Parameters)	L1	L1	L1	L0	L0/L1	L0	L1	L2
3	Cooling Water Pump	Pump 2	Centrifugal Pump	Electric Motor	Yes (Op. Parameters)	L1	L1	L1	L0	L0/L1	L0	L1	L2

Figure 3: Typical Results Summary from Asset Readiness Assessment

The fundamental of adaptation of RAO for rotating equipment regardless of greenfield or brownfield installation are based on three building blocks:

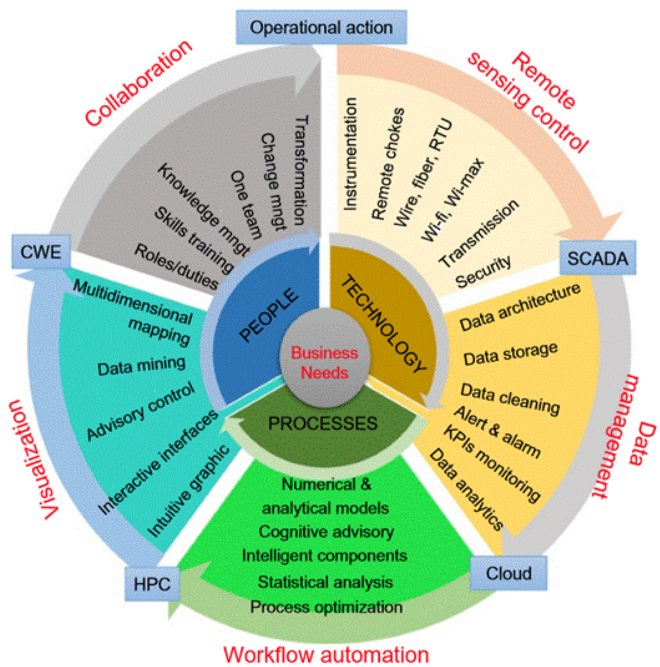
i. People - People on every facility plays an equally important role alongside Technology and Processes. People who make up the operation, should comprise of the entire team from the top management down to the technicians.
Necessary enhancements must be determined and made available to people, covering talent/people Readiness, as well as company Structure & Management, to function in a new RAO operating model before an equipment can effectively implement RAO to support its Assets/Facilities intended RAO level

ii. Process - An effective and well-design Processes must be applied in tandem with Technology in order to maximize value. For a technology that is used to digitize a poorly designed process will only result in a poorly designed digital process. On the other hand, technology application to a well-developed process will enhance its efficiency and thus enable the creation of new value.

Many process improvements concept these days have expanded to focus on the integration of processes for Operations, Maintenance, Supply Chain, and Equipment Lifecycle. As all the processes integrated, it will eventually converge into a single unified system where data is shared, processed, and integrated across the equipment management, production, and enterprise layers of the organization. This will then generate the next leap forward in flexibility and efficiency.

iii. Technology - Technology advancement is the epitome of any industrial revolutions. Advancement in technology will enable assets/facilities to achieve high degree of precision and efficiency through automation.
New digital technologies, such as cloud computing, machine learning, and the Internet of Things (IoT) are creating a hyper-connected industrial landscape where physical assets and equipment are integrated with enterprise systems to enable the constant and dynamic exchange and analysis of data.
These cyber-physical systems will enable rotating equipment to become more agile and nimble where a high degree of automation, pervasive connectivity, and intelligent systems are all become a necessity

Figure below summarized the interrelation between these 3 building blocks and its subset pillars that for the building blocks.



Notes:
HPC = High Performance Computing
SCADA = Supervisory control and data acquisition
CWE = Collaborative Working Environment
RTU = Remote Terminal Unit
WiMAX = Worldwide Interoperability for Microwave Access

Figure 4: Building Blocks supporting RAO adaptation for rotating equipment

The next step in adaptation of RAO for rotating equipment is the implementation stage. A detailed implementation plan towards realizing each RAO states need to be established and iterated over and over until the end states of RAO Maturity level are achieved as aspired. A RAO implementation plan should contain typical activities as depicted in Figure below as minimum. All these key activities should be revalidated based on highest priority and impact, to cater for the facilities business needs.

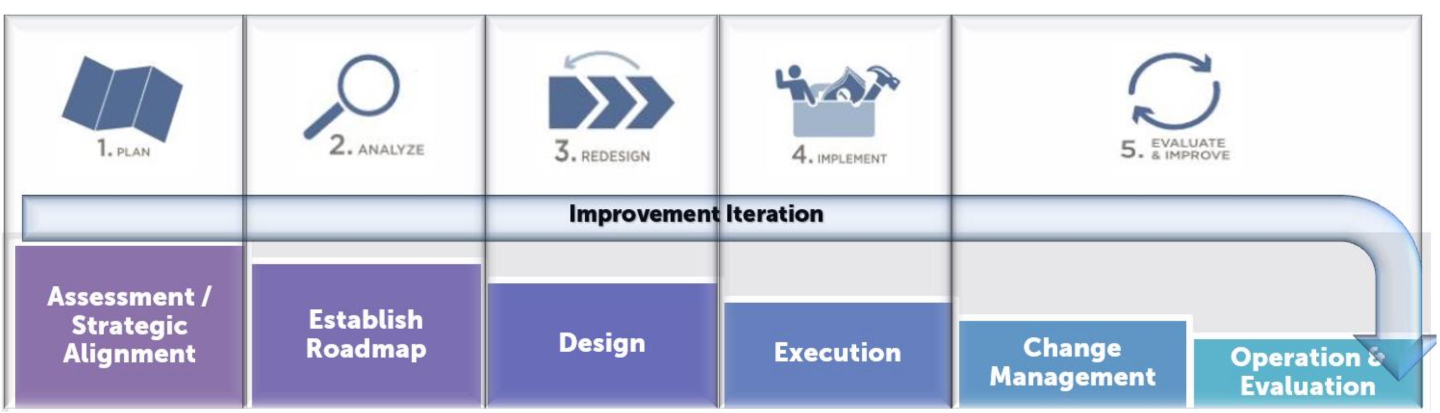


Figure 5: Typical RAO Implementation Strategy for Rotating Equipment

The implementation strategy above indicates a high level processes in implementing change in brownfield projects. These then needs to be detailed out depending on case to case basis following available guidelines in PETRONAS. This however is different from greenfield project where for greenfield project, the normal project development process are followed starting from conceptual design, feed design and EPCC execution ready for start-up. In each of the stages, there are avenues to deliberate the technical requirement and implementation strategy such as conceptual design workshop all the way to design review stage gate in detail design stage of a project.

Challenges and Lesson Learnt

Adaptation of RAO for Rotating Equipment in PETRONAS is less of a standard solution and more like a constrained but structured journey in enhancing the rotating equipment installation across the facilities to support the greater business agenda of PETRONAS in staying relevant despite the market condition, pandemic situation and regardless of how difficult or harsher the situation will be.

It cannot be denied that there are challenges in adapting the remote autonomous operations or the new way of working, especially when the current asset is already performing as per its intended design. Justifying repair works on a broke down equipment is much easier than to justify a system that would prevent a breakdown in future, its even harder when the equipment at that specific point of time is operating without a hiss. Elaborated below are among the challenges faced and the lesson learned from the journey of adapting RAO for rotating equipment.

1. People

   Workforces are the key element in any organization when it comes to supporting its business agenda including adapting to new technology in staying relevant ahead of the game. The people need to be aligned with the direction of the company in order for the company to steer the storm ahead. Therefore, when RAO is adapted for PETRONAS as a whole and Rotating Equipment specifically, first and foremost the workforce needs to be upskilled.

   There’s always a misconception that when higher level of autonomy is deployed, people will be redundant and hence out of the economic equation. This is far from true. In fact, when technology is deployed to enhance operation, it’s the upskilled workforce that will lead the change, who will analyze and provide meaningful insight from the data being minted every second and who will then have the ability to oversee multiple facilities operations at one go rather than one facility at a time. In essence, technological breakthrough has opened up new pool of knowledge such as big data analytics, but it’s the human wisdom that will make or break the change. Wisdom is not something that is available over the internet even though we have 5G connections.

   Hence, the first challenge is to augment these workforces to handle new technologies, new tools and new configurations. As the case for rotating specific, advancement of technology and big data computing has indeed enhanced the predictive ability and enabled with it a better version of prescriptive maintenance strategy. Coupled it with the wisdom of experienced and enhanced workers, will allow the company to prolong operation of rotating equipment. Insightful operation of the compressors, pumps, gas turbines, steam turbine, diesel and gas engine will then allow the company to extend inspection interval as well as time between overhaul which contributes to significant OEPX savings.

   Lesson learned throughout the adaptation is that the workforce needs to be educated not just on the benefit of the agenda, its importance to company survivability, but the importance of the workforce themselves in the journey of adapting new way of working through remote and autonomous operations. This will not only clear any doubt or misconception about RAO but will drive the workforce to further support and aligned themselves with the bigger goal to support the survivability of the company.

2. Process

   Remote autonomous operation goes beyond the hype of just remote monitoring, but rather it encroaches the area of remote control as well which for oil and gas, it brings a whole new perspective in existing instrumentation & control architecture as well as safety of the entire process system. Adapting remote and autonomous operation for rotating equipment means changing the normal operation process from manhours consuming manual feel and touch to automated sequential operation. It involves the fundamental change in philosophy of operation covering Start-up, normal operation, and shutdown including unit shutdown, process shutdown or even an emergency shutdown.

   The first challenge in doing so is to address the compliance to international code of practice such as API 14C. As an example, in API 14C, it is clearly stipulated that remote restart capability is not allowed for the following function shutdown, detected by:

   i. Level safety Low (Level LL)
   ii. Level safety high (Level HH) on sump tanks, water skimmers, flare scrubbers, and stock tanks
   iii. Temperature safety high (Temperature HH)
   iv. ESD

v. Fusible elements or other fire detection devices
vi. Combustible and toxic gas detection

These prohibitions coupled with a few more regulation from company internal standards are there for obvious safety reason inherent to the hazardous operation of any oil and gas facilities. The industry has seen just too many incidents like the of Santa Barbara (1969), Ocean Ranger (1982), Piper Alpha (1988), P-36 (2001), Usumacinta (2007) and the most notorious Deepwater Horizon (2010). As such, despite all the technological advancement, oil and gas industry remain as one of the late adopters for high automation system and let alone remote control.
Having said that, it doesn't mean that remote and autonomous operations especially the remote-control element is something to be sidelined. API 14C clearly mentioned that these prohibitions are there for "restart" situation where a confirmed incident has happened such as HH trip, LL trip or combustible gas cloud detection trip making it unsafe for a restart without positively clearing the situation. Hence the industry made it a standard to positively ensuring that all the hazards are cleared off prior to a restart. These leads to another challenge in automation of a processes, how a "positive" clear-off situation shall happen without physical presence or physical confirmation from human/people. Affordable technologies have made it possible to amplify sensors and monitoring system with redundancy installation including 8K High Definition (HD) Closed Circuit Television (CCTV), Infra Red (IR) cameras, industrial drones, micro drones, image and video analytics system which can assist the Remote Operation Centre team to positively clear-off situation due to these trips. Typical example for a rotating equipment would be the seal leak detection system. If current method or design only require one sensor to detect and trip the system, once the automation is adapted, these sensors might be doubled or tripled to ensure positive confirmation. It is also recommended to add on different type of sensing system such as, if the current leak detection relies on pressure, then for positive confirmation, it can be a combination of pressure and flow, or pressure, flow and temperature. By doing this, it will not only increase the accuracy but will also provide the required positive confirmation as per the intent of international code of practices, hence subsequently supporting the remote operation center.
These methods to positively clear off any situation however require a multi parties discussion and agreement to concur with proposed new way of working in supporting remote operations. Lesson learned are that, these agreements needs to happen at the early stage of conceptualization or when a targeted RAO level is being established for an equipment or facilities which will then assist the team during ARA assessment exercise and will then be recorded as part of gap to achieve targeted RAO level.

3. Technology

Reiterating the earlier statement that when a human / people are taken out of the plant or processes, the senses of human needs to be replaced with sensors which can provide data to achieve the same intent as to when human was there in the plant/processes. Therefore, technology act as an enabler to support remote and autonomous operations and subsequently making an intelligent system. It covers the angle of maintenance such as Equipment Basic Care (EBC), Planned Preventive Maintenance (PPM) and Condition Based Monitoring (CBM), as well as surveillance. It cannot be denied that for technology to support adaptation of remote and autonomous operations, data plays a vital role in replacing the senses of human. Therefore, data management system is another part of technology that is challenging yet critical to the overall success. Under the data management system resides the sub-division such as, data architecture, data integration, data analytics / Machine Learning (ML). In completing the technology enabler, analytics tools are the last piece of data management system which should have the following capabilities;

i. Pattern recognition
ii. Predictive analytics
iii. Fault diagnostic
iv. Prescriptive function

Supporting the adaptation of RAO for rotating equipment, technologies such as wifi supported IoT vibration sensors, motor performance sensors, bolt looseness sensors, speed sensors, oil monitoring sensors and many more are considered as means to provide continuous data for equipment monitoring. These sensors will provide data to replicate the EBC and CBM task which previously was performed manually and in some instances are recorded manually. On the other hand, IoT based CCTV cameras, microphones, drones and IR cameras provide means to ensure sufficient coverage for surveillance of the equipment or facilities. These sensors and surveillance devices generate huge data which needs to be transmitted to remote operation center for subsequent activity to be carried out such as advance analytics and insights generation. Latest development in communication technology and protocol also plays an important role in ensuring success of remote operation. IoT PLC (Weidmuller or the like) with built in gateway and communication protocol such as MQTT, OPC-UA and Node-RED are among devices that are supporting this adaptation journey. These devices enable the transferring of data from remotely located equipment or oil facility to data center or enterprise data hub through the normal fiber optic highway or the new data highway through cloud.

The main challenge in dealing with technologies and data are cyber security. As per Elgonda (2021), cybersecurity is a pre-requisite for digitalization and remote operation which need to be managed despite the real threats lingering around it. His paper went on to suggest that with a layered, Defense in Depth (DID) approach, the risk can be effectively mitigated and reduced to a level that is comparable to a traditionally operated installation. The gist is, cyber security threat is real but as an organization, it is something that need to be managed and reduced it to an acceptable level, but it should never be a showstopper for an organization to move forward with remote and autonomous operations. Lesson learned from this is that, the cyber security expertise needs to be engaged from the very beginning of the conceptual design and continuous discussion shall happen throughout the implementation stage. There is no one design fits all solution when it comes to cyber security, hence the preferred system and method deployed shall be continuously tested and secured as long as the remaining life of an equipment or facilities permits it. It is only then the company can benefits from harvesting big data to reduce the OPEX.

Conclusion

Remote and autonomous operations is the next chess board step to ensure oil and gas companies remains relevant and competitive in these challenging and unprecedented time. It is never an overnight transformation, rather it is a journey that needs a marathon spirit in ensuring the end results meets the company objective in reducing CAPEX and OPEX. Adaptation of remote and autonomous operation for rotating equipment of PETRONAS facilities will ensure the alignment with the main goal of the company. There are clear benefits in adapting RAO such as but not limited to reduced CAPEX and OPEX, increased efficiency and uptime, reduced HSE exposure and most importantly allowing PETRONAS to pivot when the market swung and pandemic hits again. The challenges with People, Process and Technology needs to be managed in ensuring the agenda and business needs remains intact. Valuable lesson learned along the way will help to steer the implementation in future and thus ensure a smooth adaptation for rotating equipment.

FIGURES

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