Autonomous solutions reduce environmental impact

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Abstract – Remote locations, hazardous environments and cost of lost time incidents are some of the drivers for autonomous facilities.

We will describe levels of autonomy and key criteria and technologies to achieve safe, controlled and maintainable operation at each level. Even though manning has a significant cost, the real cost reduction comes from increased availability and reduced maintenance. In a typical process plant, 80% of lost production is preventable, and half of this is caused by human error. As much as 30-40% of net operating cost is maintenance related and this could be reduced by 30% or more though prescriptive maintenance.

The artificial intelligence machine learning technologies that support autonomy can also be used refine equipment models. This allows us to increase energy efficiency, prevent hidden losses and reduce both normal and accidental emissions. This paper will discuss these technologies and the results for a typical oil and gas facility.

Index Terms — Autonomy, Digitalization, Environmental Impact, Emissions

I. INTRODUCTION

The petrochemical industry has been working towards autonomous facilities for well over four decades. It is often desirable to limit the need for human physical presence and intervention in industrial process plants. This new way of working may offer significant benefits to operators in terms of safety and operational efficiency, and should also reduce the cost of new installations by removing the living space for workers and support staff. Typical benefits drivers for autonomy include: [1]

1. Hazardous conditions often exist with risk of toxic or flammable gas exposure or ignition. This makes it desirable to limit human presence both for regular operations and inspection and maintenance.

2. Legacy designs often specify local control rooms and/or field control panels that necessitates local operators to be present for startup, operational changes and other operations. Often this leads to excessive flaring during startup and mode changes, and lost opportunities in implementing efficient control strategies.

3. Human operators have a high error rate for routine operations and is ideally suited to handle complex and unexpected events. Thus, a high degree of autonomy is a goal.

4. Inspection and maintenance operations should ideally be converted to condition based predictive to reduce the overall in operation failure rate, and use remote inspection and intervention solutions such as robotics and drones to handle as many tasks.

Over a long period, we have seen a gradual development from unmanned small facilities such as wellhead and satellite platforms 40-50 years ago through low and lean manning, remote operations assistance, remote operations with various levels of automatic actions such as automatic startup and mode changes. Still we have only reached what is described as “occasional autonomy” where a large number of procedures and tasks may be preprogrammed but is initiated by the operator, In facilities such as DOW/Aramco SADARA, Shell Ormen Lange and Equinor Aasta Hansteen. In the Ormen Lange Nyhamna facility this has reduced the required manning significantly, but cannot be described as autonomous plants. Even so, we have been able to reduce emissions significantly as plants may be started up without continuous flaring during the startup process.

Condition based and Predictive maintenance are now reaching the same maturity level and should result in 30-40 % reduced human time in the process, due to reduced inspection and corrective time- This is significant since most in operation failures result in unwanted release and burning of hydrocarbons, a reduced emissions rate should be achievable. These technologies have now been proven in field trials and as field machine learning is built into the systems, will be ready for use in upcoming projects. As digital twin models of the plants are developed as part of the current Digitalization focus of the industry, this execution model should significantly reduce the amount of effort necessary to implement these schemes.

A third area that should benefit from autonomy is control and optimization, and the opportunity to raise process performance to new levels. While existing systems are optimized and tuned at infrequent intervals, an on line digital twin model and description of the process, should support continuous improvement throughout the lifecycle. It is not uncommon to find improvement potential on the order of 3-8% and up to 20% have been found in certain cases such as fuel gas use for aeroderivative gas turbine driven compressors.

II. FROM LEAN TO REMOTE AND AUTONOMOUS

Autonomous systems’ is used by the industry without a common standard that defines what we mean by autonomous operations. The Merriam-Webster dictionary defines autonomous as ‘undertaken or carried on without outside control’. In the process industry we use a more accurate description of “a system that without manual intervention can change its behavior in response to unanticipated events”. This means the word unanticipated is the crucial differentiator. [2] The differentiator is that the system will be able to modify its behavior, without the need for preprogrammed responses.

Most control systems can make changes to the operation of a process in the occurrence of a pre-defined series of events. Even though the complex algorithms that make these decisions will have numerous inputs, the data is highly structured and the actions are pre-programmed. This type of response is automatic action, such as automatic startup, shutdown and mode changes. Such systems will pass control to an operator in emergency situations that cannot be handled automatically.

A. *Levels of autonomy*

There are several industry definitions of autonomy levels, but as yet no accepted international standard, For this paper we use our own company definition that our corporate research staff developed based on the automotive sector: [3]

TABLE I

Levels of Autonomy

Level	Definition of Autonomy level
5 Autonomous	Full autonomous operation occurs in all situations. No user interaction is required, and humans may be completely absent. Today, this is aspirational, and would for instance allow a shuttle tanker to mate with an unmanned FPSO to perform fully autonomous offloading
4 Adaptive	The system is in full control in certain situations and learns from its past actions to be able to better predict and resolve issues by itself. An example for such a situation could be unattended night shift operation, when no major changes to the process are expected, with remote supervisory role
3 Limited	The automated systems can take control in certain situations, referred to as limited autonomy. In this mode operators are required to confirm the proposed solutions or act as a fall back. Example would be “one button startup” procedures with remote operator alert in exceptions.
2 Occasional	System moves into occasional autonomy in certain situations. In such situations the automation system takes control when and as requested by a human operator, but only for a limited period of time. People are still heavily involved, monitoring the state of operations and specifying the targets for limited control situations.
1 Assisted	These systems provide operational assistance by decision support or remote assistance. Examples include software collaborative solutions that react to detection of instabilities and failures and may also inform a remote operations center for additional assistance
0 Manual	No autonomy, operator is in complete control, but extensive low-level automation may still be in place at this level

B. *The road to unmanned and autonomous operation*

We here want to explore how these mechanisms can affect system stability, and process performance and as a result reduce emissions, both those from normal operations, and from exceptional events. As part of autonomy, we must ensure that the underlying system is safe, controllable and can be inspected and maintained, factors which will also contribute to stable and efficient operations.

- As a basis, operation has to be safe: Safe by design and safe in operations. The basis for process safety lies in the IEC standards for safety systems IEC 16508 and IEC 16511. For the design, Failure mode, effects, and criticality analysis (FMECA) and Hazardous Operations study (HAZOP) must pay particular attention that all potential safety threats and failures can be detected and handled without physical presence. For operation, safety barrier management must ensure that the barriers built in are maintained. Process safety management uses predictive analytics and diagnostics to reveal latent and developing problems to track the safe operating state. This is also important to prevent accidental emissions e.g. due to blowdown events, as well as massive spills due to catastrophic events.

- Process operation and operational efficiency is the next step. We must ensure that the facility be operated without a physical presence? This means that all information necessary for automatic and autonomous control is available and that all necessary control actions can be performed by the system. When this information is available and represented in high fidelity model of the plant (digital twin), we also have a good foundation to check, tune and optimize the facility in a continuous improvement process. We now also have the tools to determine and implement best strategies for automatic control such as state-based controls for startup, change and shutdown, in a way that minimizes e.g. flaring emissions. Autonomous process operation would include such items as handling of consumables and reset of safety devices.

- Inspection and maintenance will have specific targets such as the frequency of major maintenance campaigns, e.g. once a year, and the frequency of minor service visits. This both has consequences for the design of the system, such as redundancy schemes and MTTF considerations, and for the way the system handles inspection and maintenance remotely. A major contribution to plant uptime comes from elimination of unplanned shutdown resulting from equipment malfunction or failure. We also need to track the many inefficiencies that can result from equipment wear and tear, such as scaling, abrasion and stiction that will affect process and equipment performance and reduce energy efficiency, generally resulting in increased specific emissions. This requires a good understanding of the wear and failure mechanisms and for autonomous facilities requires a change from periodic inspection to facility-wide condition monitoring and predictive analytics, as opposed to only tracking critical equipment as the latter is insufficient in processes with so many interdependencies.

- And, finally there are actions that cannot be handled with measurements and automatic actions but require some form of physical interaction with the plant. Remote and inaccessible facilities have demonstrated how these can be reduced to a minimum but will have to be identified and handled. Over the last 15 years many solutions have been verified in pilot projects and are now reaching TRL 6 level. This will eventually be part of the unmanned and autonomous operation, where the system can dispatch a drone for visual clarification or instruct a robot to perform some intervention such as mechanically testing a valve, scraper handling, gas detection or physical shift detection (such as ground load displacement)

- We also need a revised regulatory framework that can issue license to operate on the desired autonomy level. Today most petroleum industry legislation lack handling of levels beyond level 3.

These criteria are summarized in the following table

TABLE II

Criteria for unmanned and autonomous facilities

Criteria	Requirement
SAFETY	Can we maintain Safety: Standards, FMECA, HAZOP, IEC 61508, IEC 61511
OPERABILITY	Can the facility be operated and optimized without a physical presence?
MAINTAINABILITY	Can the facility be inspected and maintained with a limited number of service visits?
INTERVENTION	Solutions for actions that cannot be handled with measurements and automatic actions needing physical interacton.
REGULATORY	Regulatory framework for autonomy

C. *Enabling technologies*

1) Intelligent Projects and the Digital Twin As a basis, digital engineering and Digital Twin type technology should be used to model the overall system and implement the control schemes [4]. This ensures that we have good overview of the process and collect data that can later be used for Process Optimization, Condition Based Predictive maintenance and Artificial Intelligence decision making. The aim of this is not only to reduce manning in normal operations, but also to ensure that the process is running in an optimal way, and to reduce the overall number of incidents requiring (remote) human intervention.

2) Automated procedures, one button and state-based control. To reduce the load on the central process model, it is generally recommended to close have some level of edge processing where normal functions are handled by control logic in the local controller. This also gives the possibility to preprogram automatic controls with responses to common tasks and events that could be handled without complex model-based systems.

This would be in the form of sequences or state-based controls that allow startup sequences, mode changes, responses to hazardous events, workover procedures etc. to be built into the logic (based on e.g. ISA SP 95 specifications). Based on this, the central model can gradually develop autonomous capability to perform all regular operations.

One example where these technologies were employed was the Aasta Hansteen project by Equinor [5]. Part of the challenge was to make the first gas start-up process as quick and efficient as possible and eliminate flaring during startup. For this, the challenge was to reduce a sequence of over 1000 manual interventions to as few as possible. The outcome is a series of buttons that are as simple as starting a car, referred to as “one button startup”. One important experience we could draw on in this work was the recently completed Sadara complex where Dow / Aramco used state based control to achieve similar results.

During this process, the start-up steps were defined and we identified obstacles that needed to be improved. The digital twin simulator environment allowed us to do a virtual start-up of the plant, and identify numerous improvements for starting up and operating the plant in the process. In this way we managed to reduce a complex set of manual interventions to just 20 and also accomplish the “no flare” target.

The company recorded 57 specific improvements that were verified and implemented, resulting in about 40 saved days in the commissioning phase of the project, and a corresponding reduction in trouble shooting and corrections of circa 2,700 man-hours.

The next step is to establish a continuous improvement process though AI (Artificial Intelligence) Machine Learning technology to analyze and respond to abnormal events or detect hazardous process conditions and respond to them.

Some key facts [6] [7]:

- 80% of production losses can be avoided, half of which can be attributed to the wrong control decisions [5] by human operators.
- Human error has been the second most frequent cause for the 100 largest plant accidents globally over the last 30+ years.
- 14.5 billion dollars have been lost as a result of these accidents referenced above
- Roughly 3-5% of lost capacity in process equipment is caused by loss control in abnormal situations, which means a typical plant savings could be € 2.7 million annually
- Elimination of abnormal situations in petrochemical plants could increase profits by 5%

3) Predictive Maintenance For most oil and gas assets, the detailed maintenance planning for new assets is started after the design and instrumentation level have been set. This usually leads to a maintenance plan that does not take into account the technological development which is already field proven in other industries. We need to include the richness of information from smart devices and instrumentation in maintenance concepts and used during design of the asset and also change work processes to reduce the frequency of manned interventions to a minimum.

The most common practice in the industry is to apply condition monitoring to critical machinery. Each individual equipment has its own condition monitoring system which assesses the health of the equipment independently from any connected plant components. However, oil and gas facilities are complex and highly coupled systems. A problem occurring in one part of the plant can often propagate to other components, and a holistic approach to towards predictive and proactive maintenance is needed. Analytics to support improved maintenance planning can now be performed on component, system, plant or fleet levels using big data analytics and deep machine learning, where large amounts of data are processed to extract subtle, previously hidden, information. In combination with Digital Twin system modeling, the logic to support this can be extracted from the overall engineering model.

4) Artificial Intelligence and Machine Learning A fully autonomous system operating at Level 5 should be able to handle unforeseen situations and perform high-level problem solving without human intervention. Autonomous systems may require lower level automated functions in order to be effective: E.g., a robot manipulator system can learn how to pick up an object that it has not encountered before by making use of automated functions such as vision-based object detection and sensor-based collision avoidance. The robot can apply methods for robot learning [8] to learn how to safely grasp and pick up the previously unknown object.

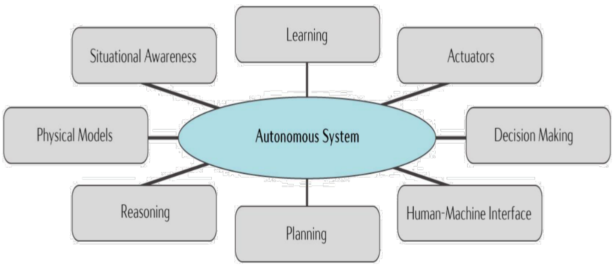


Fig. 1 Capabilities of a Level 5 Autonomous System

An autonomous system needs all or most of the following capabilities (Fig 1) [1]:

- Situation awareness: "Knowing and understanding what is going on" [9]
- Reasoning: Generate conclusions from available knowledge
- Planning: Construct a sequence of actions to achieve a goal
- Decision making: Select a course of action among several alternative scenarios
- Learning: Improvement through practice, experience, or by teaching
- Actuation: The ability to physically interact with its environment
- Human-machine interfaces: How the autonomous systems interact with humans [10]

III. IMPROVING ENERG EFFICIENCY AND REDUCED EMISSIONS

Many of the areas listed above, supporting reduced emissions using normal process operation and exceptional events could be performed during normal manual operation of the systems. We often see that optimal operation needs continuous follow up as they tend to fall out of tune or optimal control within days and weeks. This is particularly true for controls dealing with multi-phase flows, such as well control.

Even if a manual continuous improvement program can be established, an automatic and autonomous system would likely maintain an up to date dynamic model of the plant, which is ideally suited to automatically adjusted process optimization.

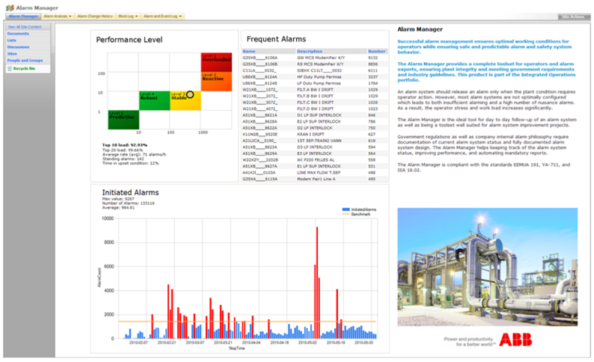
We van the summarize the emissions reduction potential of an autonomous facility as follows:

A. Emissions during safety action

One of the most important contributors to emissions from an operating facility is safety shutdown actions and the following restart procedure. Often this means that large quantities of pressurized hydrocarbons in the process must be vented to flaring systems, as systems are depressurized, purged and started up.

The remedy is of course to reduce the number of process upsets that are the cause of these events, and this is both a design issue (safe and reliable by design) and a safety management task.

This is managed by a process safety barrier management system as illustrated by the figure below.



Top 10 load: 92.93%
Top 20 load: 99.66%
Avarage rate (avg): 71 alarms/h
Standing alarms: 142
Time in upset condition: 12%

Frequent Alarms

Name	Description	Number
G35XB____6106A	GW MCS ModemPair X/Y	9132
G35XB____6106B	RS MCS ModemPair X/Y	8856
C11LA____0032_	SJEKK C11LT____0032	6111
U86XB____6124A	HP Duty Pump Permiss	3237
U86XB____6124B	LP Duty Pump Permiss	1764
W21XB____1072_	FILT.A BW I DRIFT	1029
W21XB____2072_	FILT.B BW I DRIFT	1029
W21XB____3072_	FILT.C BW I DRIFT	1026
W21XB____4072_	FILT.D BW I DRIFT	1023
A51XB____8621A	D1 LP SUP INTERLOCK	846
A51XB____8628A	E2 LP SUP INTERLOCK	786
A51XB____8622A	D2 LP INTERLOCK	750
K11NGB___6520E	KRAN I DRIFT	627
A21LICA__0190_	1ST SEP.TRAIN2 VANN	618
A51XB____8623A	D3 LP INTERLOCK	594
A51XB____8629A	E3 LP INTERLOCK	564
W22XZY___2202B	WI P200 FELLES AL	558
A51XB____8627A	E1 LP SUP INTERLOCK	531
A41KJI___0103A	LINE MAX FLOW T.SEP	498
G35XA____6115A	Modem Pair1 Line A	495

Max value: 9267
Number of Alarms: 133116
Average: 964.61

Alarm Manager

Successful alarm management ensures optimal working conditions for operators while ensuring safe and predictable alarm and safety system behavior.

The Alarm Manager provides a complete toolset for operators and alarm experts, ensuring plant integrity and meeting government requirements and industry guidelines. This product is part of the Integrated Operations portfolio.

An alarm system should release an alarm only when the plant condition requires operator action. However, most alarm systems are not optimally configured which leads to both insufficient alarming and a high number of nuisance alarms. As a result, the operator stress and work load increases significantly.

The Alarm Manager is the ideal tool for day to day follow-up of an alarm system as well as being a toolset well suited for alarm system improvement projects.

Government regulations as well as company internal alarm philosophy require documentation of current alarm system status and fully documented alarm system design. The Alarm Manager helps keeping track of the alarm system status, improving performance, and automating mandatory reports.

The Alarm Manager is compliant with the standards EEMUA 191, YA-711, and ISA 18.02.

Figure 2 Process safety management

Here the objective is to monitor that all safety related equipment is operating with the required barriers intact, early detection of potential shutdown situations and operator support functionality.

As shown earlier, 80% of process shutdowns are preventable, and half of them are caused by operator error, so autonomous systems with good safety analytics should be able to eliminate a majority of these.

It is not uncommon that such shutdowns can lose as much as 10 full production days per year, or about 3% for complex processing facilities, such as LNG plants, and about half that for average production facilities.

B. Emissions during catastrophic events

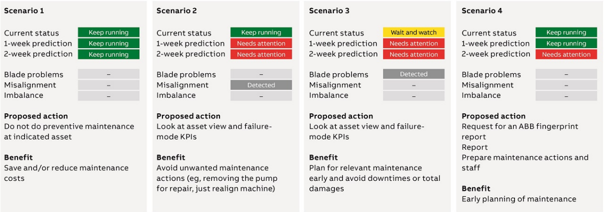
Catastrophic events that cause fires, oil and gas spills, or loss of toxic substances have caused some of the largest singular environmental impacts in the industry.

These events often result from loss of overview of the facility combined with fail to operate of critical equipment. Solutions such as the process safety management as discussed with fig. 2 above coupled with a barrier management system are invaluable in preventing these incidents. Humans excel at solving complex problems with limited data, but often fail to respond correctly to large rapidly changing data sets. Many events that are attributed to human failure, are in reality system problems that overload the operator with data that cannot be efficiently handled by humans.

C. Emissions from worn and failing equipment

Condition monitoring of industrial assets, such as motors or pumps, can ensure that critical issues are detected early, thus avoiding unplanned downtime or damage. Early intervention, which reduces the need for corrective maintenance, is more cost-effective than simply allowing a component to run to failure. [11]

Condition monitoring of such equipment combined with predictive analytics to determine the action to take in the various detected conditions. In the reference case, A neural-network-based, machine-learning model was trained to predict the future health status of the asset (an electrically driven pump).



Scenario 1

Current status	Keep running
1-week prediction	Keep running
2-week prediction	Keep running
Blade problems	–
Misalignment	–
Imbalance	–

Proposed action
Do not do preventive maintenance at indicated asset

Benefit
Save and/or reduce maintenance costs

Scenario 2

Current status	Keep running
1-week prediction	Needs attention
2-week prediction	Needs attention
Blade problems	–
Misalignment	Detected
Imbalance	–

Proposed action
Look at asset view and failure-mode KPIs

Benefit
Avoid unwanted maintenance actions (eg, removing the pump for repair, just realign machine)

Scenario 3

Current status	Wait and watch
1-week prediction	Needs attention
2-week prediction	Needs attention
Blade problems	Detected
Misalignment	–
Imbalance	–

Proposed action
Look at asset view and failure-mode KPIs

Benefit
Plan for relevant maintenance early and avoid downtimes or total damages

Scenario 4

Current status	Keep running
1-week prediction	Keep running
2-week prediction	Needs attention
Blade problems	–
Misalignment	–
Imbalance	–

Proposed action
Request for an ABB fingerprint report
Report
Prepare maintenance actions and staff

Benefit
Early planning of maintenance

Figure 3 Scenarios for predictive maintenance

Here, we illustrate three scenarios:

Scenario 1 The asset is operating normally with no damage predicted, the current and predicted statuses are "Keep running." No unnecessary time-based maintenance need be undertaken.

Scenario 2 The asset is currently exhibiting evidence of damage but not imminent failure. The current-status field advises to keep operating the asset and the predicted-status fields for the weeks ahead would show "Needs attention" and recommend an action (review the asset sensor data in a detailed fashion and to take appropriate action)

Scenario 3 The asset is currently exhibiting evidence of significant damage, not severe enough that it needs to be stopped, but enough that its condition should be monitored closely. The diagnostic algorithms indicate any initiated damage.

Scenario 4 The asset is currently exhibiting symptoms of considerable damage and could reach a significant damage level in two weeks or later. Since there is no devastating damage in the current status, it advises the user to "Keep running" and the prediction based on past historical data and current data would suggest the status field for the two-week prediction as "Needs attention."

Such systems should allow us to monitor borh for equipment efficiency and falire.

Efficiency issues might for example be scaling in pumps or heat exchangers which would turn up as deviations from the known good equipment performance envelope.

D. Emissions from Process Inefficiency

Process performance capability is an important area for gaining value and reducing emissions. Examples from 20 years of improving upstream operations at more than 40 sites give us the following indicators of the potential:

- Increase normal production 3-10%
- Reduce unplanned shutdowns ~20%
- 50% faster well ramp-up
- Reduced start-up operator load by 3600 HMI interactions at Aasta Hansteen
- Removed flaring during start-up for Aasta Hansteen
- Reduce compression cost by 20%
- Days and weeks' worth of earlier start-up

The principle behind this is often relatively simple, although the solution itself may be complex: Reduce stability, use improved operating margin to shift setpoint, as illustrated in the following figure:

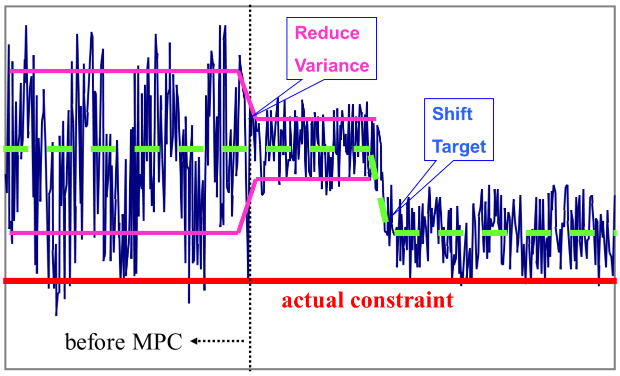


Fig. 4 Basic process optimization

As an example, the following figure illustrates how process optimization reduced the fuel gas use of a gas turbine driving a natural gas compressor by around 20%

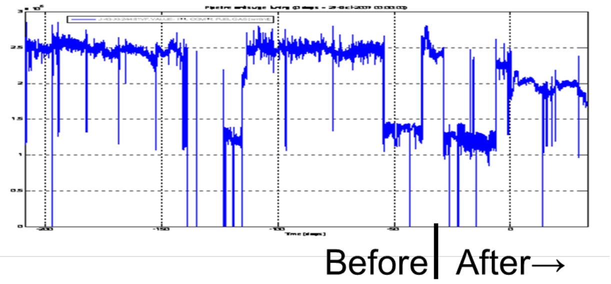


Figure 5 Fuel gas consumption reduction

However, as mentioned above such systems may fall out of optimal tuning within days to weeks, and on level 3 and above an autonomous system would provide Automatic Production Optimization analytics.

E. Emissions from Support Infrastructure

Supply Vessels, Helitransport etc.

While these emissions are not directly affected by our above technologies we would still expect a significant reduction due to reduced manning, reduced maintenance and reduced intervention needs. Therefore it still makes sense to include these in the overall emissions reductions resulting from increased Autonomy.

IV. CONCLUSIONS

The gained efficiency and loss prevention could range from 3-6% for typical well and process equipment, up to 20% in special cases. We know that the oil and gas industry on the average 12% of the well stream is consumed by the production transportation and processing facilities before the product can be sold, and based on observed figures, it is likely that more than a third of this can be eliminated with Automatic Production Optimization and Process Safety management analytics.

While part of this reduction could also be realized in a system operated by humans alone, we see that the continuous optimization that could be realized with in combination with a higher level autonomous solutions such as Digital Twin, Process Models, Machine Learning and Artificial Intelligence are likely to maintain and improve the reductions.

Higher levels of autonomy will require a detailed understanding of the tasks that will be automated when increasing autonomy from one level to the next. This includes economical impact (life of field), and the operational and safety challenges related to automating the task and removing the human from that loop. This will be based both on experience and competence .Often this can be realized by drawing on how similar challenges have been solved in other industries and applications, and who was involved (competency), how it was developed (POC Pilot – Test – Operation) and the technology deployed (algorithms, infrastructure and software).

NOMENCLATURE

FMECA	Failure mode, effects, and criticality analysis
HAZOP	Hazardous Operations study
MTTF	Mean Time To Fail

V. ACKNOWLEDGEMENTS

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VII. VITA

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