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On KPIs for efficient asset fleet management

Frederik Schulze Spüntrup[1,a,*], **Lars Imsland**[1,b]

[1] Department of Engineering Cybernetics, Norwegian University of Science and Technology, O. S. Bragstads plass 2D, 7491 Trondheim, Norway
E-mail: [a]schulzespuentrup@ntnu.no (Corresponding author), [b]lars.imsland@ntnu.no

Abstract. Fleet management exists in domains like vehicle fleet management but is not done widely in process industries. The benefits of enabling fleet management result from the economies of scale, due to better asset management and other factors. With increasing complexity, it becomes important to break down available information to a level that can easily be understood by a human. Also, it must be considered that different users of the systems in the process industry have different interests and the displayed information should be tailored to the specific role.
Based on a case study of a compressor fleet, key performance indicators (KPIs) for the assessment of asset fleets are proposed. Different dimensions from the operator to the C-level management point of view are considered. A set of KPIs is introduced and suggestions for the adaption to the specific user for enhancement of user-friendliness and user-management are made. While the KPI standard ISO 22400 mainly concerns KPIs for manufacturing operations management at plant level, the scope of this work brings the focus to the enterprise level from an operational and resource efficiency point of view.
In a further step, it is important to incorporate these KPIs into optimization and improvement measures across the fleet instead of sole visualization of information. The aim is to step towards a closer integration of different layers in the automation pyramid, such as scheduling and planning.

Keywords: Information processing and decision support, key performance indicator, energy efficiency, Maintenance scheduling and production planning

1. Introduction

In a recent study [1] Schulze Spüntrup and Imsland introduce a conceptual model for fleet asset management. In the context of process industries, a fleet concerns aggregates of a similar asset type in one company that can be operated and maintained from a fleet perspective and by doing so, the economies of scale bring certain incentive for up-scaling the number of similar assets.
During the past years, a large number of mergers and acquisitions in the global chemical industry have been observed. According to Deloitte [2] this trend will continue during the coming years. This leads to a large potential for fleet management in these companies.

Producing a product in higher quantities or by using a similar asset more often the production cost per unit decreases while operational efficiency increases. There exists a demand for fleet management tools to cope with the increasing complexity of the systems. Scheduling, monitoring and on-line coordination become a challenging task. Special focus is on the maintenance of different assets. Unexpected shut-downs lead to very expensive production losses. Therefore, the information management system has a high priority. Non-productive time of a single asset can, if redundant systems are not present, affect multiple assets in the same subsystem and the effect of each machine failure is more severe than the costs associated with its breakdown.

Asset fleets can be found in any major company in the process industry. This work is inspired by a fleet of compressors in an oil and gas company. Synergies are created by aggregating these compressors to a fleet. Other examples are fleets of pumps or heat exchangers. The interest in the industry for utilizing big data makes fleet management more attractive. Asset fleets require a paradigm change for asset management, as the fleet needs to be assessed from a top-down perspective instead of the current bottom-up approach.

The objective of this paper is to develop and aggregate certain KPIs that are helpful to operate large asset fleets. This reaches from considerations of the different hierarchical levels within a company, over the different focuses of different users up to the customizability and visualization. After giving an overview of the research in this area the case study is introduced. The methodology is explained and afterward, the identified KPIs relevant for fleet management are presented and discussed.

2. Background

In their proposed conceptual fleet management model [1] Schulze Spüntrup and Imsland state that the complexity of the information with a system that spans an entire fleet of assets is not perceivable for humans anymore. Therefore, information needs to be broken down to a top-level view which will be accessible by specific fleet management KPIs.

Galan et al. [3] introduce so-called resource efficiency indicators (REIs) for the operation of a hydrogen network. These REIs are deemed to support the decision-making of operators in the daily operation of the facilities. The different introduced REIs scope at a different level: Both plant-specific and network-wide indicators are introduced, as well as combined REIs that are functions of the network-wide REIs. The results prove that especially the combined indicators demonstrated to be efficient in decision-support.

In the work of Bauer et al. [4] the focus is towards the interface of scheduling and control with the aim of integrating these two control layers. Based on a study from the process industry, output information from the scheduling and control systems are combined and put into context. With the resulting KPI a feedback is created, and further action can be taken with the aim of optimizing the production output.

Vujanović et al. [5] developed maintenance management indicators for the application in vehicle fleet management. The aim is to increase the energy efficiency throughout the fleet. The three domains maintenance process, transport process and the environment in which the vehicle operate are considered. Indicators that improve the management decision-making are being developed and the interdependence between the different KPIs are being calculated.

The Australian Asset Management Council introduced a framework for asset management [6]. KPIs are stated as the necessary enabler to target elements such as safety incidents, asset performance or the status of asset integrity. In a complex system, the interface between human beings and performance monitoring and the improvement of the management system needs KPIs as an objective for measurement and optimization.

Fleet management will be an integral part of future ERP solutions and overall information systems as the economies of scale benefit companies that upscale the number of assets in their systems. Such a system supports all management activities on all levels throughout the company. Hereby, it is important to identify certain KPIs that can give insights into the complex system, according to Folinas et al. [7].

Schmidt et al. [8] describe a possible implementation of the ISO22400 standard for the role of KPIs in the operation of plants within the process industry. With the example of the KPI 'effectivity', the consequences for data structure systems, calculation and visualization of KPIs are discussed. It is emphasized, that the user management and usability are important factors in the success of KPIs.

3. Methodology

The process industry has been collecting information about their processes for decades. For every asset of a fleet, a dataset is available, and it contains certain measurements usually in the form of time series data. In the case of compressors, this may be rotational speed or the inlet and outlet values for pressure, flow and temperature or the vibrations of the bearings in X and Y direction. Furthermore, the statistical distribution of specific measurements can give insights, for example, the flow distribution. Based on these measurements, direct computations create new sets of time series such as the polytropic efficiency or the delivery head. These new time series can also be analyzed to obtain distributions. All the described values cannot be defined as KPIs according to ISO 22400, but they build the foundation for the KPI development and the first step of the methodology is to analyze the available data foundation.

However, data is just one side that plays a role in KPI development. Another major input is defined by the companies' strategies. While defining a strategy is the first step, the implementation of the strategy often lacks in practice. This may be because the interdependence between the strategy and the KPIs is missing. Figure 1 shows the influence of both the business and the technology side towards KPIs.

Starting from both the strategic foundations of the company and the data measurements, a methodology has been developed. This methodology is influenced by the methodology described by the theory of the Balanced Scorecard [9]. It is depicted in Figure 2.

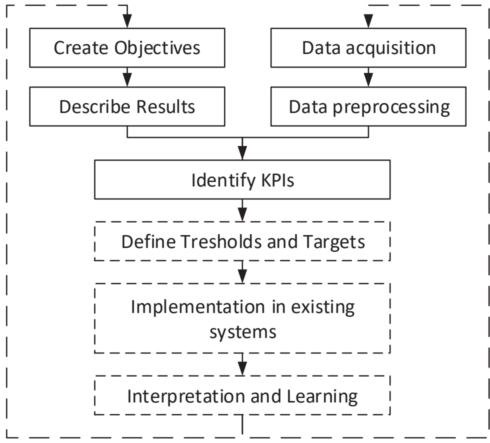


Figure 1 (left): Relation between business and technology for KPI development [9].
Figure 2 (right): Applied methodology for KPI development.

In the first step, the objectives or the strategy of the company must be defined. They can be defined on a top level, but at the same time, it is advisable to state objectives that be controlled to some extent. The different objectives should all contribute to an overall strategy. In the next step, this rough objective will be refined by describing the desired results. All defined points should focus on results instead of activities. Result-oriented language should be used to frame the objective and vague words should be removed. Everything, that can be physically perceived is appropriate to refine the objectives.

The data side, on the other hand, should be considered at the same time. The first step is to get an overview of all available data. This can be heterogeneous data from many data sources. As mentioned before, an increasing number of companies have a central storage system for their process data. As the objectives were refined, also the data can be refined. This may be first computations of the direct measurements to a more aggregated level or the filtering of noisy measurements.

The next step is merging both the objectives and the data foundation and to identify the KPIs. Each of them needs to be based on an objective and should be clearly described. The different measures can be rated in terms of their importance (Applicability, relative worth and ease of identification). It is also important to set the context of the KPI as it is done in ISO 22400 (Timing, audience, production methodology, etc.). A common misunderstanding is that KPIs that have been developed several years ago can just be adapted into the new set of KPIs. However, it is important to check if these are still aligned with the current objectives. If the old KPIs do not add value, they should be discarded.

The following three steps of the methodology are briefly described, even though the results are not part of this paper, as they are highly specific for each company and process and for data protection reasons it is not possible to give more detailed insights.

After identifying the required KPIs it is important to define targets (if a decrease or increase is an objective) and thresholds (if the process should be stabilized, e.g. for a KPI concerning quality). In the next step, this system needs to be implemented, e.g. in a Balanced Scorecard structure. It needs to be ensured that the KPIs are updated on a regular basis. For continuous data sources such as process data this is simple, but for discontinuous data like lab reports, it is even more essential to ensure these updates. The last step is the interpretation and the learning. Interpretation is possible after the visualization of the KPIs. Standard practices to do so are automated reporting and dashboards.

4. Case study

Even though asset fleets are present in all kinds of process industries, this work is based on the example of an offshore compressor fleet for gas production. The asset fleet is located on the Norwegian continental shelf on more than 40 offshore platforms. While all the compressors are part of a distribution network, each platform is operating independently. On each platform, there are several compressors, mostly arranged in one train, sometimes two trains of compressors. After the gas has been separated from oil and water, there are still remainders of these two fractions in the gas. The compressors are operated in conjunction with one or more scrubbers. Scrubbers remove traces of liquid droplets from gas streams to protect downstream equipment from damage and failure. The compressors re-compress the gas to a higher pressure before finally, the export compressor pumps the gas into the export pipeline.

The total amount of nearly 200 turbine-driven centrifugal compressors in the fleet is operated with a mixed time-based and condition-based maintenance scheme. Real-time process data is stored in a central information management system and can be used for further processing. Other discontinuous data is also available, e.g. via SAP or other systems.

5. Results and Discussion

In the following, the methodology that has been described earlier is applied and the most relevant steps are shown and discussed in this work. Without going too much into the details of and tailoring the solution too specific into goals of one Oil and Gas company, different strategies of Oil and Gas companies [e.g. 10, 11, 12] are compared and key points are adapted for this study.

Main points of these strategies are indeed very similar. The companies want to reduce operational expenses, grow production output and emitting less carbon dioxide throughout their production processes. Another focus is also on modernizing the assets by implementing digital technologies. While the latter is working as an enabler, the focus of the KPI development in this study will be in the other three areas.

The data availability in the given case study is as follows: While there is a central Information Management System available, not necessarily all assets have the same measurements available. This leads to inhomogeneous data. Next to regular process measurements (e.g. inlet and outlet temperatures, pressures, etc.), vibration measurements are available for most of the compressors. Furthermore, discontinuous data is available from lab measurements. Nonetheless, the choice of different KPIs is heavily influenced by the availability of different measurements. One aspect is due to the inhomogeneity of the available measurements in the fleet which causes a dilemma between applying high-accuracy calculations and involving all assets within the fleet. There is, therefore a balance to keep between what is desirable (with perfect data) and what is possible in practice.

Since the focus of this work is not on regular KPIs but on fleet KPIs, the comparison between different assets becomes more interesting, as it drives decision where future investments should be taken or which assets are from a technological or financial point of view unrealistic to operate. Benchmarking becomes, therefore, an integral point of assessing the fleet. Therefore, all KPIs can be used and not just their value over time is interesting, but the comparison against the "best-in-fleet" value and the "state-of-the-art" value. When setting up a visualization dashboard, it should always show the existing gap between these benchmark partners.

Regarding the objective of reducing the carbon emissions a KPI is suggested that is comparable to the KPI "Comprehensive energy consumption" suggested in ISO 22400. The "emission intensity" is a value that is calculated for specific fields. It has the unit "kg per kg of oil equivalent energy use" and measures the emissions of produced carbon dioxide per produced unit with an energy content equivalent to a kg of oil. Introducing a KPI that tracks how much carbon emission every specific asset creates, helps to identify assets that have a particularly bad carbon dioxide balance and they may be exchanged with more efficient model types of the same asset class. The comprehensive carbon emission is defined as follows with PQ as the produced quantity.

$$e_{CO_2} = \frac{\sum(CO_2 \ emissions \ during \ a \ production \ cycle)}{PQ} \quad (1)$$

For the objective of decreasing operational expenses, there are two KPIs suggested. The first one is the lifetime asset cost. All expenses of a specific asset are summed up. This includes the capital expenses for the asset itself, but also all expenses for planned and unplanned maintenance. From a fleet perspective, this gives insights into the weak spots of the fleet, as those will require more maintenance than other assets. From the data point of view, it is possible by crawling information from systems such as SAP. The lifetime asset cost (LAC) is defined as follows and involved the terms of installation cost (C_{ic}), start-up cost (C_{su}), operation cost (C_o), maintenance cost (C_m) and the decommissioning cost (C_d):

$$LAC = C_{ic} + C_{su} + C_o + C_m + C_d \quad (2)$$

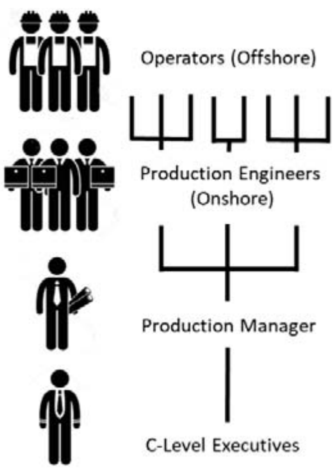
The other suggested KPI is the continuous implementation of the remaining useful lifetime of an asset or the average useful lifetime of an asset fleet, respectively. The calculation of a remaining useful lifetime of a compressor, for example, can be based on measurements such as vibration measurements. [Heng2009, Kurse2013] With ongoing research in this field, the prognosis will become more accurate. The implementation of this KPI will give an overview of the status of an asset fleet which is both easy to grasp and very tangible. Furthermore, this KPI does not just have a function from a managerial perspective, as the RUL is an important input for the scheduling and planning of maintenance actions. The average useful lifetime for a fleet is defined as the mean of all fleet assets' RULs and can help managers to make decisions like increasing investment into new assets (with higher lifetime) starting a change management process to improve proactive maintenance.:

$$\overline{RUL} = \frac{\sum_{i=1}^{n} RUL}{\#Assets} \tag{3}$$

The field of increased production output is strongly connected with the two other major topics. An example KPI can be the specific utilization of an asset. With respect to the given case study, an important KPIs derives from the operation of the compressors. The amount of time they are in surge mode or when the recycle loop needs to open is giving insights into the way how the asset is operated. As wear and tear is an important topic for the lifetime of an asset, it is also interesting to observe the number of starting and shutdown procedures. Specific events like operation in surge mode or shutdown and startup-procedures can be detected via pattern recognition algorithms. Operation modes such as the compressor recycle ratio (CRR) can be calculated as the ratio of the recycle flow to the inlet flow of the compressor system.

$$CRR = \frac{\dot{V}_{recycle}}{\dot{V}_{in}} \tag{4}$$

An important realization while working on the development of different KPIs for fleet management is the fact that different user groups have different personal objectives, a different scope and see themselves in different responsibilities. Therefore, it is important to consider the different user groups that are interested in the assets. While the operators' interest is mostly in the reliability of the assets on their platform and maybe the comparison towards other platforms, the production engineers care also about the operational integrity of the assets, the overall condition of all compressors in the fleet and the efficiency of specific assets compared to the top-performing assets in the fleet or the state-of-the-art in order to facilitate the decision-making process of changing specific assets. The production manager is already at a stage where single assets are not the focus of interest anymore, as the entire production becomes more and more complex. Decisions of a production manager are mostly based on the knowledge of experts with the support of various KPIs.



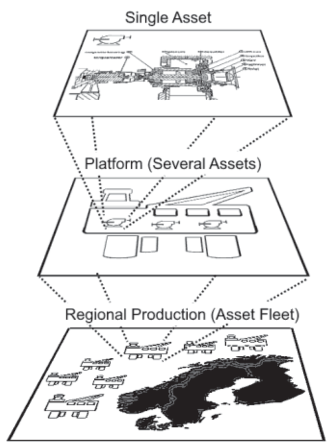


Figure 3 (left): Hierarchical overview of stakeholders in an Oil and Gas company
Figure 4 (right): Dimensions of a fleet

The conceptual fleet management model in [1] provides several interfaces in which KPIs could be used for the integration to other layers. Integrating the RUL of all assets within a fleet into a maintenance scheduling or planning approach gives huge benefits. Furthermore, KPIs are the only way for efficient visualization of fleet data, since other means would be to complex for humans to understand.

6. Conclusion

Based on the example of a compressor fleet, this work presented how to develop KPIs for fleet management. After giving a brief overview of related research, a methodology is introduced and based on this methodology a few example KPIs are derived. These KPIs aggregate information from a fleet and help to operate this fleet with the objective to improve the reliability of the fleet, decrease carbon emissions and to increase the overall production output. Furthermore, the challenge of varying users for such KPIs is posed. With different hierarchical level, the interests of the users differ. Thus, the KPIs need to be adapted and for each specific user an individual overview must be given, showing the right dimension within the fleet.

Next to enabling a better operation and management of assets in a fleet, these fleet KPIs are the starting point for the integration of different control layers. As briefly discussed in the result section, higher control layers such as scheduling and planning can benefit from having fleet KPIs as input values for the optimization of e.g. maintenance schedules and plans in time-scales from months to several years.

Future work to that follows up on this study is to gather a group of domain experts and to evaluate the different KPIs with the decision making and trial evaluation laboratory (DEMATEL) approach, possibly refined by a linguistic evidential modification, as it was done in the study of Si et al. [13]. This will enable to draw an influential relationship diagram of the different KPIs and in the end to determine which KPIs do not give new insights to reduce the complexity of the system itself.

7. Acknowledgement

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References

[1] Schulze Spüntrup, F. and Imsland, L., “Asset fleet management in the process industry - a conceptual model” in *10th Advanced Control of Chemical Processes - ADCHEM18*. Shenyang, 2018.

[2] Deloitte, “2017 Global chemical industry mergers and acquisitions outlook - Driving forward through global uncertainty”, 2017.

[3] Galan, A. et al., “Resource efficiency indicators usefulness for decision-making process of operators: refinery hydrogen network case study in *Proceedings of the 27th European Symposium on Computer Aided Process Engineering - ESCAPE27*, 2017, pp.1513–1518.

[4] Bauer, M. et al., *“KPIs as the interface between scheduling and control*” in *IFAC-PapersOnLine*, 2017, pp.687–692.

[5] Vujanović, D. et al., *“Evaluation of vehicle fleet maintenance management indicators by application of DEMATEL and ANP”* in *Expert Systems with Applications*, 39(12), 2012, pp.10552–10563.

[6] Australian Asset Management Council, *“Framework for Asset Management”* Hawthorn, 3122 Victoria, Australia 3122, 2014.

[7] Folinas, D., “*A conceptual framework for business intelligence based on activities monitoring systems”* in *International Journal of Intelligent Enterprise*, 1(1), pp.65–80. 2007.

[8] Schmidt, W. et al., *„Key Performance Indicators (KPIs) in der Prozessindustrie – Anwendung und Implementierung“* in *14. Fachtagung EKA – Entwurf komplexer Automatisierungssystem*., 2014

[9] Rohm, H. et al., *“The Institute Way: Simplify Strategic Planning and Management with the Balanced Scorecard”,* 1st edition., The Institute Press, 2013.

[10] BP plc, 2018, BP Strategy [Webpage]. Available: https://www.bp.com/en/global/corporate/what-we-do/our-strategy.html [Accesses: 1 July 2018]

[11] Chevron Corporation, 2018, Chevron Strategy [Webpage]. Available: https://www.chevron.com/annual-report/2017/strategies [Accesses: 1 July 2018]

[12] Equinor ASA, 2018, Equinor Strategy [Webpage]. Available: https://www.equinor.com/en/how-and-why.html [Accesses: 1 July 2018]

[13] Si, S.L. et al., *“Identifying key performance indicators for holistic hospital management with a modified DEMATEL approach”* in *International Journal of Environmental Research and Public Health*, 14(8), 2017.