SuREBPMS

Sustainable and resource efficient business performance measurement systems – The handbook

PRODUKTION2030

Sustainable and resource efficient business performance measurement systems – The handbook

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BOXES

There are THREE TYPES OF colored boxes in the handbook. See below what they represent.

PITFALLS **SOLUTIONS** **INFORMATION**

Introduction

Virtually every company has implemented some kind of Business Performance Measurement System (BPMS), with the purpose of monitoring production and business performance and executing business and corporate strategy at all levels in a company. A majority of these BPMS emanates from a multi-dimensional scorecard integrating operational development principles, such as Lean production and can be defined as:

“A business performance measurement system refers to the use of a multi-dimensional set of performance measures for the planning and management of a business” [1]

Recently, focus has also been put on Sustainable Production, adding more frameworks and indicators for companies to administrate. The ongoing trend is that the number of measures constantly increases, but the question is if this trend increases the effectiveness or if it supports the systematic strategic development of a business. The trend of increasing complexity in both BPMS and the production system, together with the need of flexibility in meeting new challenges and demands, raises a number of challenges:

- How should a BPMS be designed to allocate minimum amount of resources required for collecting data, analysing, and reporting information?
- How to use the BPMS to understand opportunities, to trigger activities, and to develop decision support for improvements?
- How to manage and support a dynamic behaviour and continuous update of the performance measures in the BPMS?
- How to integrate the perspective of sustainability on shop floor level in a company?

Based on these challenges, the research project Sustainable and Resource Efficient Business Performance Measurement system (SuRE BPMS) was initiated. This handbook will summarize some of the discussions and results from this project. The name of the project indicates the two-fold scope:

- Development of BPMS allocating minimum amount of resources to design and to use while maximizing the understanding of what should be done to improve the operational activities.
- Development of BPMS integrating the perspective of sustainability on shop floor level in a company.

We hope that this handbook will provide some new insights on how to design, implement, use, and revise your Business Performance Measurement System (BPMS) towards better decision making, directing operational improvement efforts to where it’s needed the most, while allocating less resources to manage it. We also hope to guide you on how to find indicators suitable for driving sustainability improvements from a bottom-up perspective.

This handbook primarily targets production managers, XPS champions, and middle managers in large and medium sized companies within the manufacturing industry. However, both SMEs as well as any private or public organization could benefit from understanding and applying the principles presented, even though specific examples are from another context.

The outline of this handbook takes it starting point in the motivation to measure performance and the importance to link the design and target setting to the manufacturing strategy. The KPI lifecycle is used to describe the design, implementation, use, and revision phases of a BPMS, where the following symbols represent different parts of the handbook:

Purpose of measuring

Strategic implications

Overview of the KPI lifecycle

The Design phase

The Implementation phase

The Use phase

The Revision phase

We would like to express our sincere gratitude to the industrial project partners Alfa Laval in Lund, GKN Aerospace Engine Systems in Trollhättan, Haldex in Landskrona, Volvo Cars Engine Plant in Skövde, Volvo Construction Equipment in Arvika and Braås, Volvo GTT and GTO, ÅF, and Sandvik Mining and Construction for their great contribution during the project and for all the inspiring discussions concerning challenges, pitfalls, and remedies. During the project, a series of case studies has been performed together with the partner companies and we especially appreciate the support from Torgny Almgren, Pernilla Amprazis, Stefan Braunias, Nico Dima, Per Gabrielsson, Henrik Kloo, Conny Larsson, Andreas Myrelid, Veikko Turunen and Johan Valett during these case studies.

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Carin Andersson,
Project Manager

Measures, Indicators and KPIs

A measure is the direct result of a measurement activity that is performed to acquire data or information, while an indicator is often compiled using two or more measures, thus being more aggregated and useful for predicting or estimating and behaviors. For example, each data point in a control diagram is a measure, while the trend of the curve in the diagram is an indicator.

In practice in industry, these terms are mixed and all measures and indicators used for decision making or reporting are called performance indicators or key performance indicators (KPIs). It is unrealistic that all these indicators are "key" but KPI has become a commonly accepted term. The term measure will be used to denominate the result of a measuring activity and a measure can therefore become a KPI or be aggregated or mathematically transformed to a KPI.

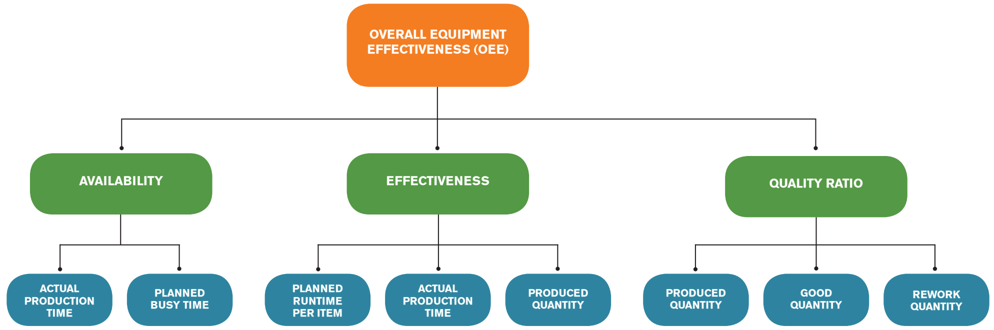
According to the ISO standard 22400 [2] the base for building a KPI are elements, being the lowest level in the hierarchical structure building up a comprehensive or high level KPI. The elements can correspond to measures e.g. by calculations or identification of conditions or they can be set by requirements. Elements or measure, being different time elements in the illustrated example to the right, can individually be subjects of improvements on a very local and basic level in a production system.

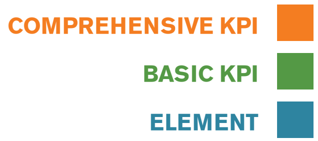
Basic KPIs, being e.g. equipment availability or quality in the right hand example, is an indicator based on a few basic elements. These provide more information about the status of the processes, also providing a wider range of improvement opportunities.

Basic KPIs can be integrated or aggregated into comprehensive KPIs, by e.g. a mathematical formula. KPIs are almost always associated with goals used for reporting, benchmarking, or improvement triggers. If using a comprehensive KPI to drive improvement work, an understanding of the elements and basic KPIs building up the comprehensive KPI is necessary.

Everyone does agree on that KPIs are vital to provide the information needed to explain and communicate a company's progress towards the stated goals. What is sometimes forgotten is that a support infrastructure is needed to operate the BPMS. Measurement equipment is needed, as well as databases for storing the information, analytical tools to transform data to information, and meeting procedures for taking actions. This infrastructure can be manual or digital using different IT-systems. More information about this is found in the Use section of this handbook.

Sustainability is an important theme for this handbook and all aspects of environmental, social and economic sustainability are considered. These dimensions of sustainability are interconnected and in our studies, 90% of existing KPIs were found to have a relation to sustainability.





An example of how a comprehensive KPI (OEE) is built up by basic KPIs and elements based on ISO 22400.The KPIs can be structured in a hierarchy where measures and other elements, such as planned busy time, are used to calculate basic KPIs and basic KPIs are used to calculate comprehensive KPIs.

ISO 22400 "Automation systems and integration – Key performance indicators for manufacturing operations management"
The ISO standard 22400 defines 35 KPIs, primarily for use in automated production in the manufacturing industry. An important contribution of the standard is that a large number of elements are defined. These elements are typically different time or amount elements. There is a great need in industry to standardize these terms, because there is usually no consensus within each company about definitions of elements like lead times, cycle times and scrap amounts. If these definitions are not standardized, it is hard to gain acceptance for the BPMS.

The purpose of BPMS

There are three major purposes of KPIs: Report, Control and Improve. Some KPIs may be useful for all these purposes, while others are only for one purpose. These purposes exist on all different hierarchical levels in the company and for all different functions. However, the following description is focused on the production and the production support functions.

REPORT
There are several purposes of reporting such as:

- Mandatory reporting based on legislation.
- Other public reporting such as Annual reports or CSR (corporate social responsibility) reports.
- Benchmarking, for example between factories in the same company group.
- Internal reporting.

Internal reporting is represented by measures that are passed on to the level above and not necessarily used for direct control, e.g. *Energy consumption* and *Number of accidents*.

Accidents are obviously handled on the level where they have occurred, but the measure of the number of accidents is only reported upwards.

CONTROL
Production control occur at all levels and with different time scale. From the measure of a specific quality parameter in a machine that is used to adjust the process, to monthly follow-up of delivery performance at factory level to control that the delivery requirements are met. A control activity is performed to secure that a measure is within the acceptable interval, and is therefore always connected to control limits, upper and/or lower limits, defining an acceptable interval.

IMPROVE
Improvements can be of different magnitude: From small, continuous improvements to large investment projects. KPIs provide an understanding that improvements have been achieved.
There might be a need for new, specific KPIs to make sure that the improvements reach the strategic objectives. For example: The strategic objective is to be flexible. Flexibility, in this case, is measured indirectly through a KPI for the service level to the customers. To become more flexible, it is determined that the set-up time must become shorter. A new KPI to measure the set-up time must be defined to be used in the improvement project, but before and after the improvement project there is no need to measure the set-up time itself.

SILO MENTALITY
There are several pitfalls linked to the manufacturing strategy process. One is to not define suitable attributes to the performance objectives, leading to different interpretations among people at the company on what is meant by each objective. This will also lead to differences in interpreting the KPIs linked to these attributes.

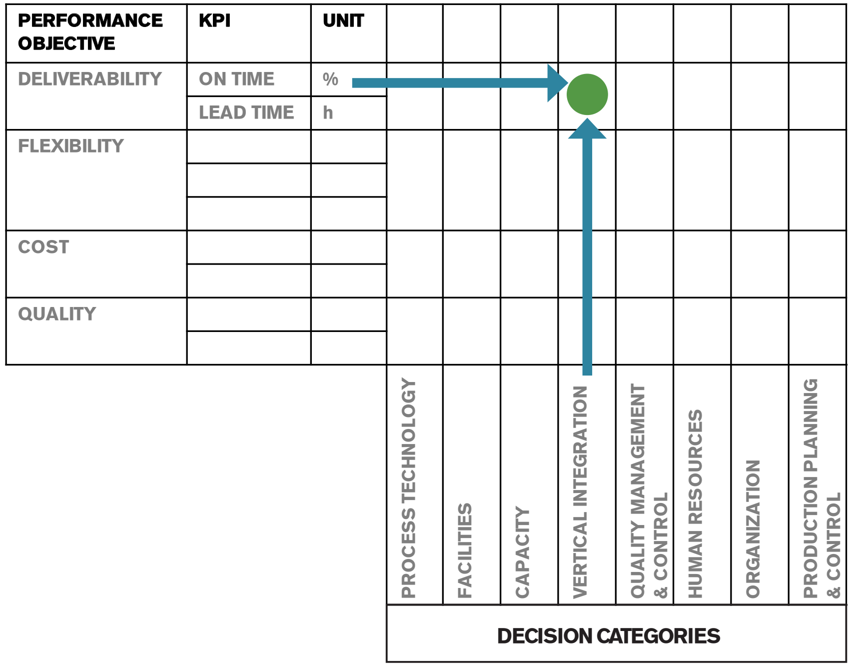
Manufacturing strategy

Manufacturing strategy is the way we, at operational level, decide to meet the targets set at corporate and business levels. Manufacturing strategy links the corporate and market objectives to the production resources, so that decisions being made are in congruence with targets and that targets are being set that are based on what is possible to achieve. Strategic improvements need to be within reasonable reach considering present capabilities and investments. It is important to create a two-way communication between goals and capabilities when developing the manufacturing strategy.

The task is to have an ongoing matching or reconciliation between the performance, regarding manufacturing objectives, and the operational capabilities. Finding the right BPMS to do this is naturally central. Every performance objective may have several KPIs, which need to be measured in order to track the performance. What do we mean by quality? Do we find quality problems during production and measure it as rework or scrap? Or do we send products to customers getting feedback as reclaims instead? Another example, related to flexibility, may be product flexibility measured in terms of number of products or variants, product mix flexibility measured as the ability to run different products in the same production cell or line, or volume flexibility showing the ability to increase or decrease the production volume.

The figure to the right shows an example of how to do the matching between performance objectives and decision categories. The performance objective deliverability is often considered very important, but in this case two KPIs are needed, on time delivery and lead time. These KPIs are measured and described with their measured units, % and hours respectively. When looking at the decision categories, we can see that all decision categories may affect the deliverability. Taking on time delivery and vertical integration as example, the question is "How important is good supplier control for achieving on time delivery?" This has to be investigated and suitable actions can be made to improve the performance up to the desired target.

NON-DEFINED ATTRIBUTES
There are several pitfalls linked to the manufacturing strategy process. One is to not define suitable attributes to the performance objectives, leading to different interpretations within the company on what is meant by each objective. This will also lead to differences in interpreting the KPIs linked to these attributes.



Each performance objective and attribute is more or less dependent on all decision categories. Example: How important is good supplier control (dealt with in the vertical integration) for achieving on time delivery?

Management systems

The use and improvement of the BPMS are closely connected to the management systems for e.g. environmental, quality, and occupational health and safety management, as well as to operational development (OD) programs (e.g. continuous improvement initiatives). If the different certified management systems are integrated with each other and with OD-programs, it is recommended that the organization for the management system also take care of the operation, maintenance and development of the BPMS.

To engage the whole organization, top management should delegate selected responsibilities of the BPMS control to the appropriate operational level. Motivation to participate in data acquisition and improvement work is promoted if each team is responsible for setting targets and define the measurements for efficient control of their unit. To communicate progress to and receive feedback from management the teams and units also need to report KPIs upwards in the organisation to higher levels where aggregated or specific targets needs to be known.

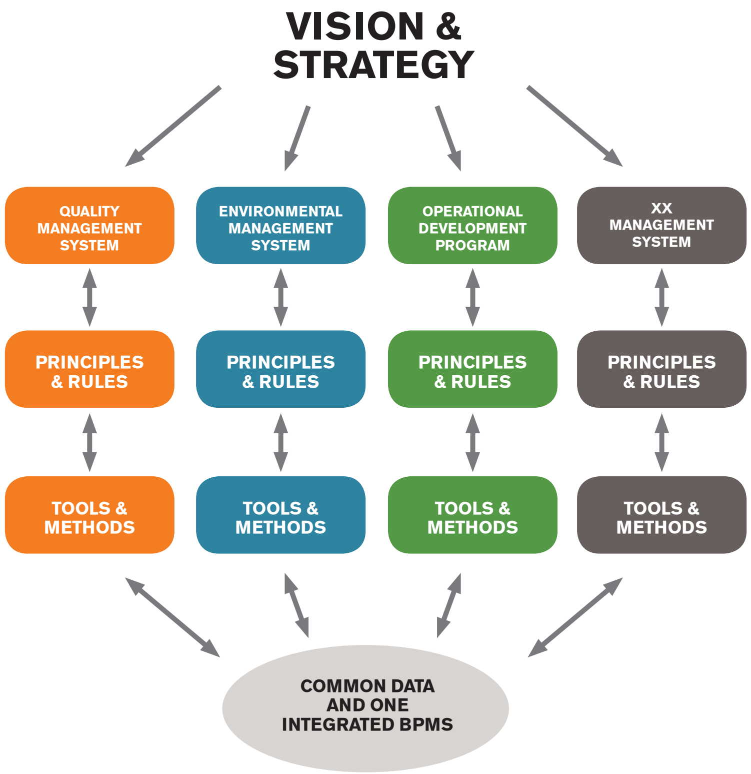
However, often are management systems and OD-programs not fully integrated and contain different sets of KPIs. Although policies and visions may be aligned, the connections to the strategic business process may be inefficient. The use of different tools for similar purposes such as different ways to do risk analysis for safety, quality and economy is common, as well as different ways to map production processes.

Success factors for operational development are:

- Management involvement
- Training and education
- Employee empowerment
- Alignment to long term strategy

In addition, to succeed with alignment of BPMS in the operational systems:

- Focus on the improvement cycle (Plan-Do-Check-Act)
- Connect BPMS development to production development
- Take ownership of measurement standards
- Ensure integration with the operational development methods and tools
- Make use of internal auditing



The vision and strategy must be the common base for all principles and management system rules. The methods and tools needs to be in line with these and the KPIs need to be appropriate for the tools and methods as well as give correct feedback for strategic decisions.

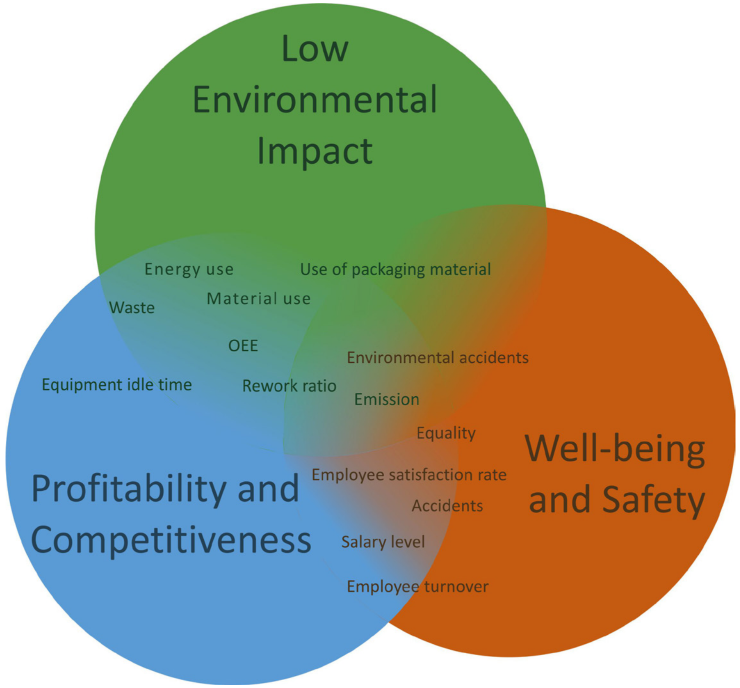
Sustainability

Sustainability is a growing concern for manufacturing industry and is usually explained as a three-dimensional concept as illustrated to the right. A sustainable corporation aim for low environmental impact, care about people working at or being influenced by the company, and still remain competitive. The basis for sustainable manufacturing operation is to create high values while using less resources. In that perspective is resource efficiency a virtue of every manufacturing operation. Wasted resources do not add customer value and represent costs to the enterprise and society in general. However, the challenge is to link sustainability improvements on the operational level to financial results and sustainability improvement on corporate level. An increased sustainability awareness is promoted by integrating more sustainability KPIs on lower company levels, and communicating these upwards in the organisation.

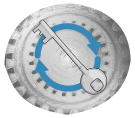
As shown on the right-hand side, sustainability KPIs are not only environmental KPIs such as measures of emissions or energy consumption. The manufacturing company can take conscious steps towards a more economic, social and environmental sustainability by defining KPIs that drive behaviour and improvements in all three dimensions. Many of the commonly used production KPIs focusing efficiency and productivity can, if defined properly, be used to monitor and improve environmental sustainability, leading to lower levels of energy and resource use.

To move towards more Sustainable and Resource Efficient BPMS, the following steps are recommended:

- The BPMS enables sustainable manufacturing by including KPIs covering a broad scorecard with the sustainability dimensions of economic, social and environmental perspectives.
- The BPMS enables sustainability by including KPIs supporting proactive decisions instead of reactive reporting.
- The BPMS enables sustainability by widening the perspectives including development processes and aligning the BPMS to manufacturing strategy and objectives.
- The BPMS is sustainable in terms of resilience to change where a dynamic behaviour and continuous update of the KPIs in the BPMS are enabled and encouraged.
- The BPMS is resource efficient as cost efficient efforts are spent on collecting data, analyzing and reporting different information and decision making.
- The BPMS is resource efficient by encouraging use of standards and best practice.



There are many KPIs that influence two or even three of the sustainability dimensions.



The KPI life cycle

There are many elements that go through distinct life cycles, e.g. equipment that is developed, produced, used, returned, disassembled and produced and used again. Also KPIs have a lifecycle of design, implement, use and revise as illustrated to the right.

The Manufacturing strategy is the starting point of the KPI life cycle. A BPMS should communicate and deploy the strategy by appropriate measures leading the organisation towards the strategic purposes and goals. Before developing any individual KPIs, the manufacturing strategy needs to be in place and commonly understood.

The first step in the BPMS life cycle, is to understand what should be measured and how. A well designed set of KPIs should provide the information you need to make better decisions, answering e.g.:

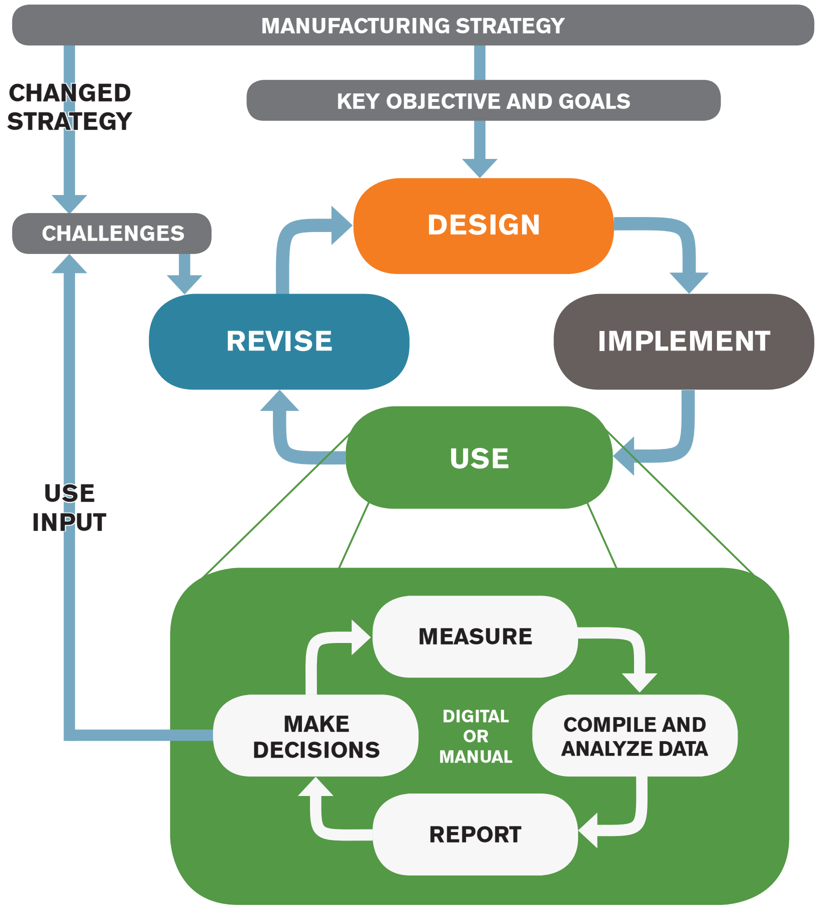
- Are we doing the right things?
- Are the things done in the right way?

Implementing the selected KPIs is a delicate task and will have less success if you do not get the whole organization on board. Finding the triggers and work procedures for engaging and motivating the organization is the path to success.

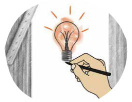
The Use phase is the central BPMS phase with the purpose of monitoring and transferring information within the organization to prioritize and initiate actions to meet the goals and purposes of the manufacturing strategy.

Within the use phase, Measuring is about establishing the right objectives and assign ownership to the measures, as well as ensuring data availability and quality. Compile and analyze is the prerequisite for establishing information and an understanding of how to act to improve. Using variation as a tool, analyzing trends and understanding root causes are important elements. Establishing a scheme for Reporting information to the right stakeholders and the right time will support decision making. A good visualization of a measure will provide information about improvement opportunities and how to prioritize between actions.

The manufacturing strategy should never be static, and the new knowledge the KPIs provide about the operation should initiate a Revision of both the goal levels and the set of KPIs. For example, if excessive amount of downtime is caused by equipment setup, a new temporary KPI measuring setup time is required, together with goals for this KPI and actions to increase the setup efficiency. This KPI should be removed when the target has been reached.



The KPI life cycle.



Design
- The BPMS Framework

The initial phase of the BPMS lifecycle deals with the design: what should be measured and how should it be measured? The BPMS design concerns four levels:

- BPMS architecture and key perspectives.
- More specific set of KPIs in each perspective.
- Individual KPI definition.
- KPI target value.

The set of KPIs is developed in a deployment/feedback-process aligned with overall vision, objective and goals, as illustrated [3]:

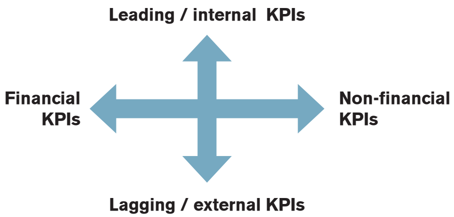
The Balanced Scorecard is probably the best known of the multi-dimensional performance measurement frameworks developed in the late 1980s and early 1990s. The aim was to be more proactive and emphasise a balance between financial, internal, non-financial and external measures.

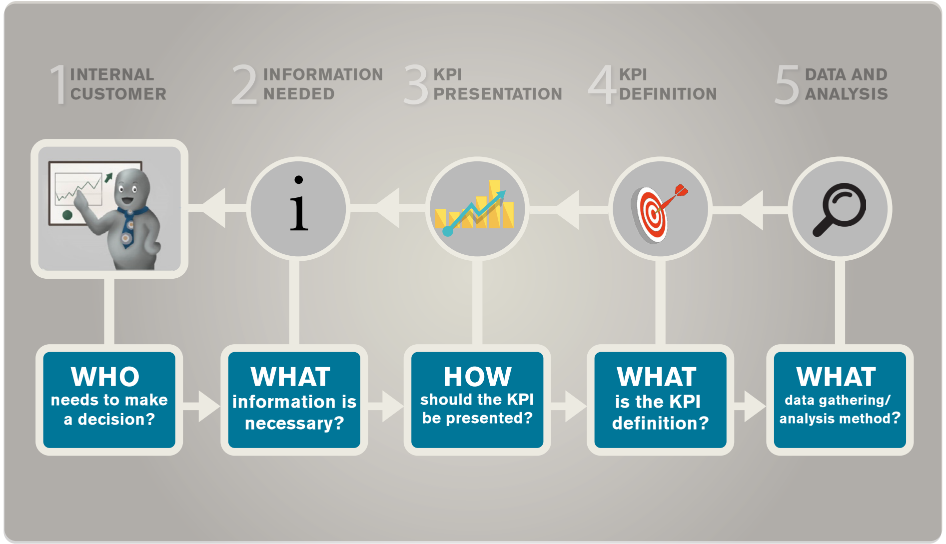
FINANCIAL AND NON-FINANCIAL KPIS

A classic set of perspectives in a BPMS is given in the Balanced Scorecard, including Financial (cash flow, sales growth, operating income, return on equity etc), Customer (% sales from new products, on time delivery, customers' ranking etc), Internal business processes (cycle time, unit cost, yield, product introduction etc) and Learning and growth (time for product development, product life cycle, time to market etc).

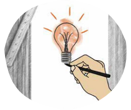
LAGGING AND LEADING

Lagging indicators are typically "output" oriented and external KPIs concerning effectiveness dimensions; if the right work is done altogether. Leading indicators are typically "input" oriented and internal KPIs concerning efficiency dimensions of analyzing if work is done in the right way. Leading indicators will in the end influence the lagging indicator.





It is essential to have a PULL-approach when defining the KPIs. Start thinking about who needs to make a decision, since the KPIs should assist in the decision-making. The next step is to decide what information is necessary for that decision-maker and how it should be presented to convey the information in the best way. First when this is clear it is time to define in detail what properties to measure and how.



Design
- Defining KPIs

There is now a strong consensus that KPIs should be derived from strategy. In addition, it is central to develop the KPI based on the use and need of information for decisions. On an overall level, literature mentions two general usage areas of KPIs [1]. First, the KPIs should support in measuring the success of the implementation of the defined strategy. Second, the information and feedback from the KPIs should be used to challenge the assumptions and test the validity of the strategy.

When designing the KPIs, it is worth having **SMART** objectives in mind [4], meaning they should be:

Specific	A specific area for improvement.
Measurable	Quantify or at least suggest an indicator of progress.
Assignable	Clear who will do it.
Realistic	results that can realistically be achieved, given available resources.
Time-related	Specified when the result(s) can be achieved.

Name	First pass yield (FPY)
Objective	Improve quality
Description	The first pass yield (FPY) designates the percentage of products, which full fill the quality requirements in the first process run without reworks (good parts). It is expressed as the ratio between good parts (GP) and inspected parts (IP).
Formula	FPY = GP / IP
Unit	%
Target value	(range 0-100%) 2017: 97%
Frequency	Reported every shift
Source	Inspection station
Who report	Operator at inspection station
Who acts	Manager

KPI definition template with First pass yield as an example.

KPIs SHOULD:

- Be related to the company's objectives and manufacturing strategy.
- Support the comparison of organizations which are in the same business.
- Acknowledge differences between departments, sites and circumstances.
- Be under control of the evaluated organizational unit.
- Provide fast feedback.
- Stimulate continuous improvement rather than simply monitor.
- Be selected through discussions with the people involved (customers, employees, managers).
- Have a clear purpose.
- Have clearly defined data collection and calculation methods.
- Be simple and easy to use.
- Preferably be ratio-based and not absolute.
- Preferably be objective and not subjective.

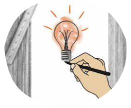
ENVIRONMENTAL KPIs

The current practice of environmental KPIs suffer three typical shortcomings:

- **System level:** KPIs are well represented on site or company level, less on work station and team level.
- **Topic:** KPIs are well represented on energy usage, less on material efficiency.
- **Frequency:** KPIs are well represented in annual environmental reports, less in daily improvement efforts.

WITNESSED PITFALLS TO AVOID WHEN DESIGNING KPIs:

- **Too many KPIs. There is a tendency to add KPIs but not to remove. This creates unclear priorities and confusion.**
- **Unclear or complicated definition of KPI. This can create lack of accuracy and non-intuitive actions, but also loss of acceptance and misuse of the KPI.**
- **KPIs that are not possible to influence on lower levels. Creates loss of acceptance and frustration.**
- **Measuring what is available, not was is needed. From a technology point of view, massive amount of data is available. The relevant analytics and synthesis of data is the challenge.**
- **Sub-optimization. Optimising on a KPI in one part of the value chain might create negative consequences for another.**

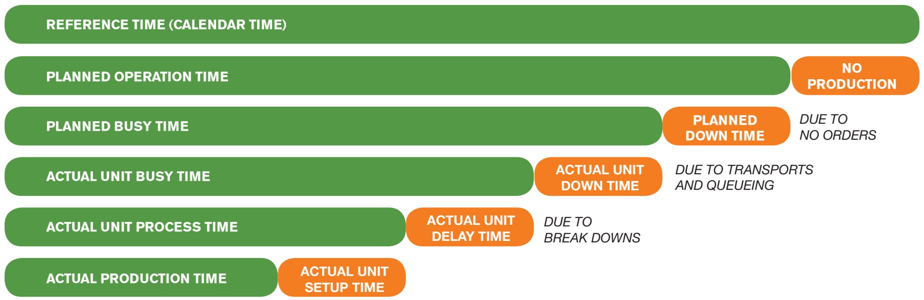


Design
– Basic Elements

Elements are the measures and set values that are used to calculate KPIs. Some elements can act as KPIs by themselves. A pitfall when designing KPIs are that they are not clearly defined and understood. This can happen when the perception of the elements in a KPI differs in the organisation. For example, people in the same organisation can have different ideas about what cycle time (or “Planned run time per item” according to ISO 22400) is. Does it include the material handling? Does it include disturbances? These and similar uncertainties have a large influence on the BPMS as a whole as the elements are used to calculate KPIs and are aggregated upwards in the organisation.

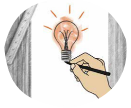
Most elements are either times (e.g. Processing time) or amounts (e.g. Products produced). The elements presented in this section are some of the elements that are standardized in ISO 22400. The authors recommend companies to use these, but any elements might work as long as they are well defined and standardized within the company.

It is essential that every company uses well defined elements, if not, there will be a constant discussion within the company about the validity and effect of different KPIs.



The time bar model explains how the different time elements from the ISO 22400 standard are related to each other. The model shows how the planned operation time is the sum of all other time elements and can be used as a tool to visualise where most of the productivity losses are created.

TIME ELEMENTS	
Planned busy time	The planned time when a work unit can produce products
Planned run time per item	The planned time for producing one product
Planned scrap quantity	The number of expected process-related scrap
Actual unit delay time	Time for unplanned stops due to e.g. mal-function
Actual unit setup time	Time for preparation of a work order
Actual personnel attendance time	The time that the personnel is available to work on production orders.
Actual personnel work time	The time a worker needs to produce one production order
Actual order execution time	The time from start to end of a production order
Actual production time	The time that a work unit is producing
Time between failures	The busy time between two consecutive failures at a work unit
Time to repair	The time a work unit is unavailable due to failure
Corrective maintenance time	The time when corrective maintenance is performed at the work unit
Preventive maintenance time	The time when preventive maintenance is performed at the work unit
AMOUNT ELEMENTS	
Produced quantity	Number of products produced in a production order
Scrap quantity	Produced quantity that do not meet the quality requirements and needs to be scraped
Good quantity	Produced quantity that meets the quality requirements
Rework quantity	Produced quantity that do not meet the quality requirements but can be reworked to meet the quality requirements
Storage and transportation loss	Number of products lost in storage or transportation
Inspected quantity	Inspected quantity
Raw materials inventory	Amount of material that will be transformed into finished goods [kg, m^3 etc.]
Finished goods inventory	Amount of finished goods that can be delivered [kg, m^3 etc.]
Consumable inventory	The amount of material that is consumed during the production process [kg, m^3 etc.]
Consumed material	The amount of material that has been consumed in the process [kg, m^3 etc.]
Work in process inventory	The amount of material that is assigned to a production order
Failure event count	Number of events when the work unit is unavailable due to failures
Equipment production capacity	The maximum number of products that can be produced in a production equipment during a set time period



Design
- Recommended KPIs

The KPIs in the following list are based on ISO 22400 and complemented with KPIs from the literature as well as KPIs used by the companies participating in SuRE BPMS. The KPIs are sorted into different categories to stress the importance of balancing different perspectives in the BPMS.

All the KPIs are not intended to be used on all hierarchical levels and generally it is recommended to use as few KPIs as possible.
The purpose of this list is to serve as inspiration in the design phase. The KPIs may have to be adjusted or specified in order to suit your company.

FINANCIAL

Inventory turns	Measures the average number of times the inventory stock is replenished and is used as an efficiency measure. *Inventory turns = throughput / average inventory*
Scrap and rework cost	The value of rework and scraped products
Manufacturing cost per unit	The cost of producing on unit

HUMAN RESOURCES

Actual personnel attendance time	The time that the personnel is available to work on production orders.
Absence from work	Percentage or amount of employee absence due to different reasons.
No. of training hours per employee	How much time is spent on training the employees
Employee satisfaction rate	Often measured by an employee satisfaction survey
Male to female ratio	Indicates the share of male or female employees
Employee turnover	The number of employees leaving their job divided by the average number of employees
Overtime	Measures the amount of overtime

IMPROVEMENTS

Level of housekeeping	Often measured using monthly 5S audits
Number of suggestions per employee	The average number of improvement suggestions made by the employees
Number of implemented improvement suggestions	How many of the improvement suggestions have been implemented

PRODUCTIVITY

Worker efficiency	Describes the relationship between the time the employee works and the attendance time. *Worker efficiency = Actual personnel work time / Actual personnel attendance time*
Throughput rate	How much time it takes for one quantity to pass through the production system. *Throughput rate = Produced quantity / Actual order execution time*
Overall equipment effectiveness	A comprehensive KPI that Indicates the efficiency of a work unit. *Overall equipment effectiveness = Availability * Effectiveness * Quality ratio*
Availability	Indicates how much of the planned busy time that the production unit is actually producing. *Availability = Actual production time / Planned busy time*
Effectiveness	Indicates the relationship between the planned cycle time and the actual cycle time. *Effectiveness = Planned runtime per item * Produced quantity / Actual production time*

QUALITY

Quality ratio	Shows the share of the produced products that meet the quality requirements. *Quality ratio = Good quantity / Produced quantity*
Actual to planned scrap ratio	Shows how much of the planned amount of scrap that is actually scraped. *Actual to planned scrap ratio = Scrap quantity / Planned scrap quantity*
First pass yield	The percentage of the inspected products that fulfills the quality requirements without rework. *First pass yield = Good quantity / Inspected quantity*
Scrap ratio	Shows the share of the produced products that are scraped. *Scrap ratio = Scrap quantity / Produced quantity*
Rework ratio	Shows the share of the produced products that requires rework in order to meet the quality requirements. *Rework ratio = Rework quantity / Produced quantity*
Storage and transportation loss ratio	Share of products lost during storage and transportation and the amount of consumed material. *Storage and transport loss ratio = Storage and transport loss / Consumed material*

FLEXIBILITY

Batch size	How large batches are produced
Percent of employees cross trained to perform all tasks	How many of the employees are trained on all tasks in e.g. A work unit
Percentage of personnel from temporary work agencies	The number of personnel employed by temporary work agency in relation to the total number of personnel
Number of models produced in one line	How many different models can be produced in the same production system
Late order changes	How many orders are changed late in the process
Actual unit setup time	Time for preparation of a work order

DELIVERY

Produced quantity	Number of products produced in a production order
Percentage on time delivery	Indicates the share of deliveries that are done on time

EQUIPMENT

Mean operating time between failures	Statistical indication of the mean operating time between failures. *Mean operating time between failure = ∑ Time between failure for a work unit for all failure instances / (Failure event count +1)*
Mean time to repair	Statistical indication of the mean operating time it takes to repair a work unit. *Mean time to repair = ∑ Time to repair for a work unit for all failure instances / (Failure event count +1)*
Corrective maintenance ratio	Indicates how much of the total maintenance time that is spent on corrective maintenance. *Corrective maintenance ratio = Corrective maintenance time / (Corrective maintenance time + Predictive maintenance time)*
Equipment load ratio	Indicates how much of the capacity of an equipment that is used. *Equipment load ratio = Produced quantity / Equipment production capacity*
Actual unit delay time	Time for unplanned stops due to e.g. mal-function

SPEED

Actual order execution time	The time from start to end of a production order
Actual unit busy time	The time that a work unit needs to execute a production order

SUPPLY CHAIN

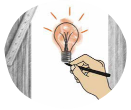
Customer complaints	How many complaints are received from the customers
Customer satisfaction	Often measured by a customer satisfaction survey
Supplier quality	How much of the material received from suppliers meet the quality requirements
Supplier delivery on time	How many of the deliveries from suppliers are on time

SAFETY

Accidents	Number of accidents with injury
Incidents	Number of incidents without injury
Eliminated risks	Number of eliminated safety risks

ENVIRONMENTAL

Water use	How much water is used
Recycled water ratio	The share of recycled water used
Energy use	How much energy is used
Renewable energy fraction	The share of renewable energy
Use of packaging material	How much packaging material is used
Share of reused or recycled material	How much of the material is reused or recycled
Waste	Amount of waste of different types e.g. Consumables, hazardous waste
Emission	kg of emission of e.g. Ozone depleting substances, green-house gases, and other environmental affecting gases
Material use per unit of production	kg/PU or m2/PU, can be different types of material



Design
- Setting targets

Targets need to be set for all KPIs. For some KPIs the target level is obvious and therefore unnecessary to state explicit, for example the target for number of accidents (should be zero).

There are many targets where the ultimate goal is given, for example everything that can be 100%, such as Delivery accuracy. However, for several reasons the company may choose not to set it to 100%, but rather a lower value. The value can be based on one or several of the following principles, and there is not one best solution:

- Top-down breakdown from strategic objectives.
- Bottom-up calculation to get a theoretical ideal value.
- Historical data: averages or best observed.
- Best practice in business.
- Challenging levels to promote continuous improvements.

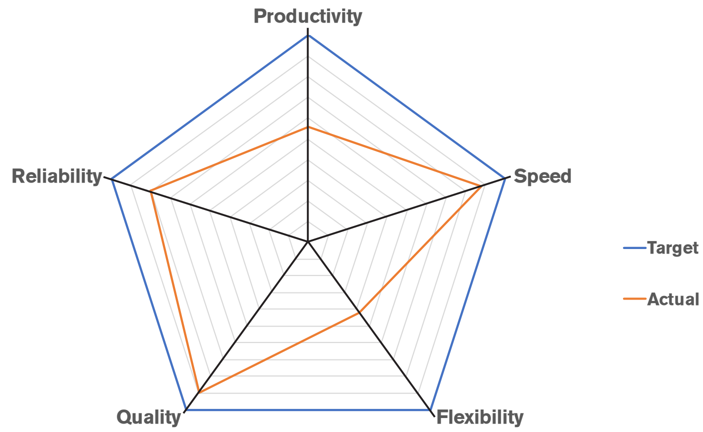
Setting target levels is not an easy task and there are a number of factors that complicate the target setting:

- Targets cannot be set appropriately without knowing current and future process capability.
- Targets do not explain how to improve performance.
- Targets provoke cheating, including either distortion of the data or distorting the way the work gets done.

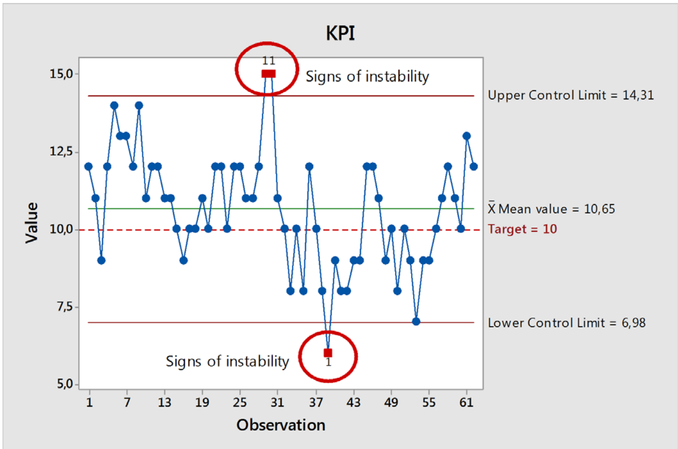
Setting targets is always a compromise between different objectives and the interest of different stakeholders [5]:

- If set too high, targets create stress and de-motivation;
- if set too low, targets encourage complacency;
- if imposed, targets are unlikely to be owned by those who have to deliver them; and
- if negotiated, there is an incentive to press for lower targets that are easier to meet.

ONLY HISTORICAL BASES FOR TARGETS
Goals that are set only based on historical results combined with an arbitrary annual improvement lacks relevance and potential to control and improve the operation. Historical data can be a starting point for the goal level, but this data needs to be combined with decided operational improvement initiatives and the improvement these are expected to result in. This will lead to a higher level of ambition since results of every improvement initiative are explicitly connected to the goals of relevant KPIs.



A spider web diagram can illustrate goal categories and the actual present level.



A control chart is a way to understand the variation in different KPIs.

Implementation

A successful implementation is dependent on creating understanding and motivation bringing everyone to be involved, in a strategy deployment process. The presence of management is of crucial importance to establish motivation throughout the organization. The clarity of the management´s message and setting reachable goals are triggers for motivation as well as to improve for the sake of the company and the employees. Showing how practical examples of improvements have positive effects will support involving the workforce in measuring activities.

SETTING UP WORK PROCEDURES
Work procedures for data collection, visualization and aggregation need to be developed. Based on the KPI definition the data sources for the separate elements needs to be identified, also the data quality should be secured. If the data is not already available, it is preferable to set up an automatic digital data acquisition solution. If that is not possible, templates for manual data acquisition should be carefully designed. It is better to measure manually than not measuring at all.
The transformation of data into information and further into understanding is crucial to be able to decide on actions to take if targets and goals are not met.

A bottomup flow of information needs to be established through aggregation of lower level KPIs (see the right hand illustration). Equally important is the top–down feedback of reactions, actions and changes based on the information and understanding this brings about.

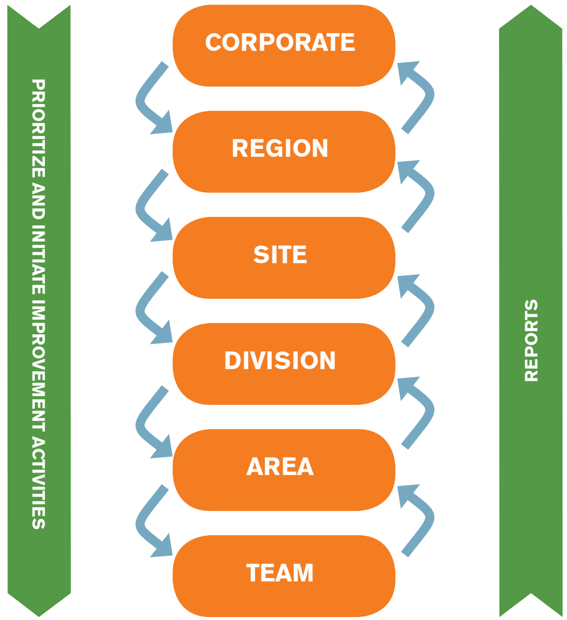
DEFINE ORGANIZATIONAL ROLES
The functionality of the BPMS is dependent on a clear distribution of roles and an engaged organization running, maintaining and revising the system. Employees need to be assigned responsibilities for data collection, aggregation, visualization, and reporting, as well as to identify and initiate activities.

EDUCATING THE ORGANIZATION
The organization needs to have a common view and understanding of what to measure, how and why. In addition, each stakeholder involved needs to clearly understand their role and responsibility in the process. The education and preparation therefor have to encompass the following:

- The link to the corporate and the manufacturing strategy.
- The definition of the KPI and its elements, as well as how the result should be interpreted.
- Information about the different roles, clarifying who should be communicating with whom.

ESTABLISH A METHOD FOR DATA COLLECTION
Taking the right action is dependent on the quality of the data acquired. The data source should also be considered.

CHOOSE OR DEVELOP IT SUPPORT
An IT-based automatic data acquisition solution is highly preferable. If that is not feasible a manual method needs to be put in place. Manual data acquisition systems provide less reliable and accurate data and is more time consuming, both to acquire and to visualize and aggregate.



The strategy deployment process and feedback though reports.

Transformation of data to understanding for reporting.

Use
- Measure

Several types of elements might be needed to calculate a KPI and these could come from different data sources. Some elements are not measured, but rather set, such as “Planned runtime per item”. Based on the definition of a KPI and the elements included in the mathematical formulation, the data source for each element needs to be identified. For example, “Percentage on time delivery”, should the information be gathered by the shipping personnel at the company or by the receiving personnel at the customer? It depends on who is responsible for the logistic services.

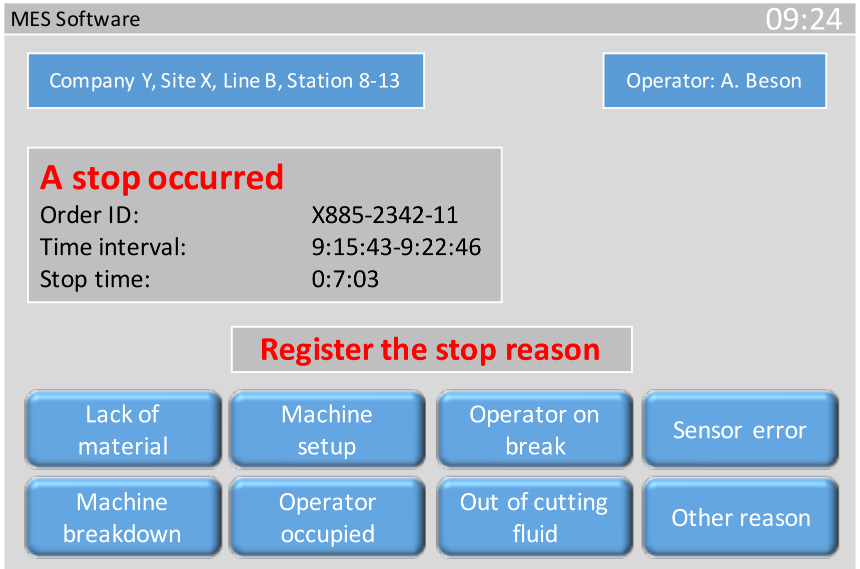
The data source might be manual or automatic. An IT supported automatic data acquisition solution is preferable. If setting up a digital data acquisition solution is not feasible, manual methods need to be implemented. To support standards procedures and homogenous data input, templates should be designed and clear and concise instructions developed to support the employees in understanding how and what to measure. It should be noted that manual data acquisition methods might provide less reliable data and are more time consuming when it comes to calculating and visualizing KPIs.

Since the purpose of monitoring should be to improve, the data collection system should also include information about e.g. reasons for downtimes or speed losses if OEE, tact or productivity is monitored, or reasons for quality defects if quality is monitored. This is needed to initiate the appropriate improvement activities. To conclude:

- Reliable data need to be retrieved for each element in the KPI definition. If data is not currently collected or available in any company database, data acquisition needs to be installed and secured.
- Automatically operated digital data acquisition solutions are preferable, but it is better to monitor manually that not monitor at all.
- Data collection should not just be to register a number or a value but also additional information for guiding further improvement actions.

MANUFACTURING EXECUTION SYSTEMS (MES)
Data acquisition software is usually a part of a Manufacturing Execution Systems (MES). The MES integrates the data collection with the production planning system. The technological development of data acquisition technology is fast, sensors and communication devices get faster and cheaper. Common technology today for data acquisition:

- **Bar and QR codes with optical readers**
- **RFID (Radio-frequency identification)**
- **Optical, inductive, or mechanical sensors**
- **PLC or machine control system data**



An example of an interface of a data acquisition software. It is very important to have clear definitions of all the stop reasons, and further to use the registered data to actually eliminate frequent disturbances. If the operator feels that the information isn't used, he or she will not bother to register correctly.

Use
– Compile and Analyze

Your KPIs should help you to understand how your organization is performing in comparison to the corporate visions and goals and guide you to the right actions. For the KPI to assist in the decision-making it is necessary to first define the decision-makers and state what information is needed as well as how it should be presented to convey the information in the best way. First when this is clear it is time to define what properties to measure and how. That is the foundation for being able to compile and analyze the KPIs in the best way.

LEADING AND LAGGING KPIS

One should also reflect upon if the KPIs are lagging or leading. Lagging indicators are typically "output" oriented, easy to measure but hard to improve or influence. In a business context an example of a lagging indicator is revenue. Leading indicators are typically "input" oriented, harder to measure but easier to influence. The increase in quality defects could be an example of a leading indicator that in the end would influence the lagging indicator revenue.

VISUALIZING VARIATION

To present the data in a way that it is understandable and at the same time contains as much information as possible could be a challenge.

However, as an example, by visualizing variation using e.g. a control chart, much more information about the process will occur. It will show if the process is stable, predictable, and only contains chance causes of variation. If the process instead is unstable, it is unpredictable. From a decision-making perspective, it is important to understand the difference since they call for totally different actions. An improvement of a stable process often requires a change of the entire process, a decision made on a high management level. Improving an unstable process, containing one or a few unpredictable and traceable causes of variation, is often possible at shop floor level.

Different types of variation.

USING AVERAGE VALUES

It is common to use aggregated, average values on KPIs. Sometimes it is only displayed as a two-point-comparison, stating if the target was reached or not. There is a risk of asking the wrong questions and keeping the organization busy trying to eliminate random variation in vain.

DISPLAY VARIATION

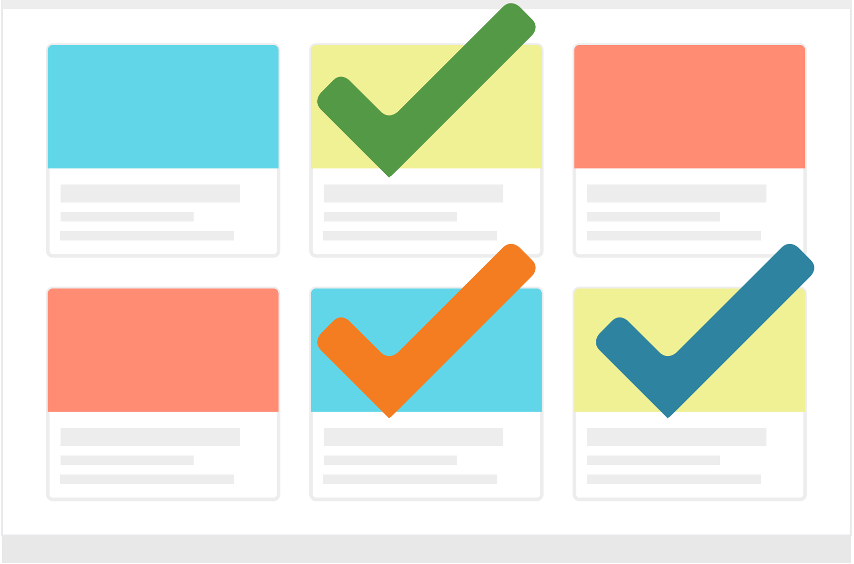
If variation is displayed, e.g. by using a control chart, the manager will be able to ask the right questions to reveal causes instead of symptoms. The focus will be on the process, the variation and any signs of instability. A BPMS could benefit threefold when adopting this way of analyzing and presenting the data. Firstly, by getting the ability of guidance on suitable actions. Secondly, is the possibility of prediction, since a stable process can be expected to deliver within the control limits. Finally, is the opportunity to monitor a process and get a warning signal if the process changes and becomes unstable.

Use
– Report and Make decisions

REPORTS
There are many stakeholders to each organization who need reports about the operation. Most stakeholders are internal, i.e. part of the same organization, but there are also external stakeholders that require reports, such as tax authorities and environmental organizations. The reports have different purposes depending on the stakeholders' interest. Some are for making direct decisions, e.g. how much carbon tax the company should pay, while other data reported externally may be for analysis and actions that lay much further in the future. Most reports used in the daily operation are communicated in oral form and maybe documented by the KPI value only on a whiteboard.

Checklist for reports:
- Decide on a structure of reporting that is easy to understand.
- Decide on an appropriate reporting interval (can differ between measures and purpose of reporting).
- Provide different stakeholders with right information.
- Differ between measures that should trigger action on the level collected and those that will be reported to other corporate levels or external stakeholders.

MAKE DECISIONS
Checklist for decision making:
- Secure engagement from decision makers by reporting the right thing to the right stakeholders.
- Review performance and create a list of action to remedy problems or reach targets.
- Prioritize between actions.
- Decide on targets for prioritizing and use tools for different targets (e.g. cost simulation for cost targets).
- Discuss scenarios for what could be gained or lost if an action is postponed in time.
- Discuss risks and benefits of different causes of action.
- Do not focus on only each measure and hitting the numbers, a systems view is sometimes necessary to adopt.
- Follow up if a decision led to the intended effect.



Digital dashboards can be used in decision making.

Revise

Performance measures should reflect both the internal and external environments of organisations. As the competitive environment of a company changes, the KPIs must be adjusted accordingly. Organizations often add KPIs more frequently than they delete them and therefore the set of KPIs need to be continuously evaluated and questioned. The BPMS and KPIs can be revised on four levels [1]:

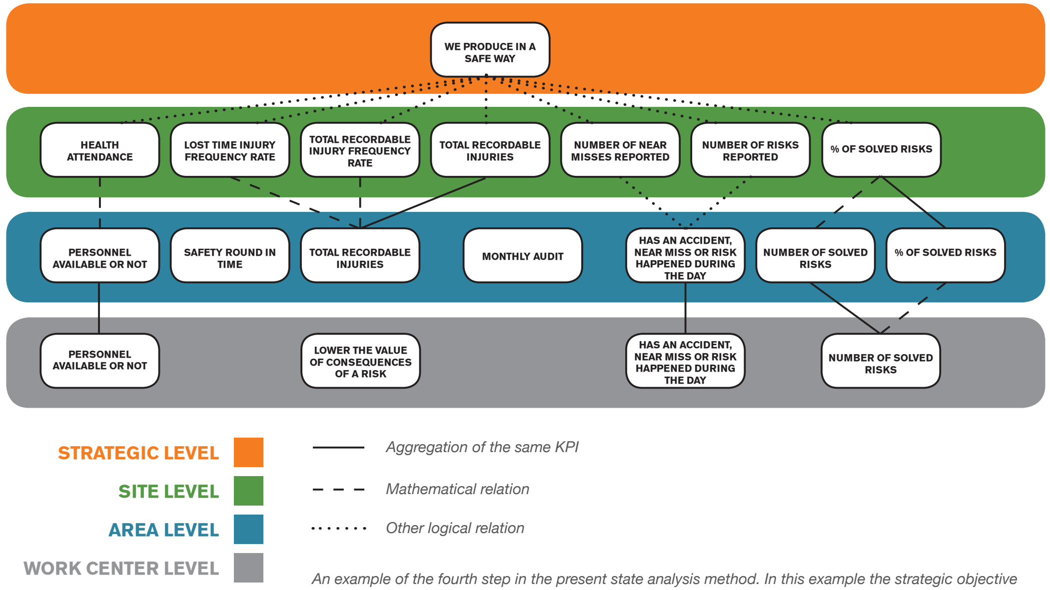
A. Revision of the strategy, PMS architecture and cascading structure
B. Revision by omitting or adding KPIs.
C. Revising an individual KPI definition.
D. Revising the KPI target value

In order to manage BPMS revisions, five factors should be considered [6]: culture, processes, people, systems and triggers. The culture within the organization should ensure that the KPIs are used, appreciated and relevant. There need to be processes in place for reviewing, modifying and deploying KPIs. It is also necessary that the people in the organisation have the required skills to use and revise the BPMS and that there are information systems that are able to handle the appropriate data. Finally, triggers represent changes in the internal or external environment that initiate a revision of the BPMS.

PRESENT STATE ANALYSIS METHOD

To perform the revision on level B and C, a present state analysis method with four steps can be used:

1. Management interviews: The strategic goals and the BPMS structure is identified and described.
2. Mapping of KPIs: All KPIs used at all hierarchical levels in the organisation is mapped and documented in a standardised way.
3. Rationalization potential: All mapped KPIs are compared to determine if there are KPIs measuring the same thing or having the same purpose. The purpose of this step is to identify redundancies and standardise KPI definitions within the organisation.
4. Interrelations between KPIs and strategic goals: The relations between KPIs on different hierarchical levels and to the strategic goals are identified and visualised (see figure on next page). This analysis shows how well the strategy is deployed throughout the organisation and if there are any missing KPIs in relation to the strategy. It also identifies the KPIs that are not related to any goals or other KPIs.



An example of the fourth step in the present state analysis method. In this example the strategic objective "We produce in a safe way" is related to KPIs on site level, area level and work center level. There are three different types of relations, aggregation, mathematical and other logical relations. Some KPIs are not clearly related to the other indicators or the strategic objective.

About 2 % of the total work time in the companies studied in the research project is spent on meetings where the results of KPIs are discussed. Therefore, it is important to revise the KPIs regularly to maintain an efficient BPMS so that only relevant information is discussed during these meetings.

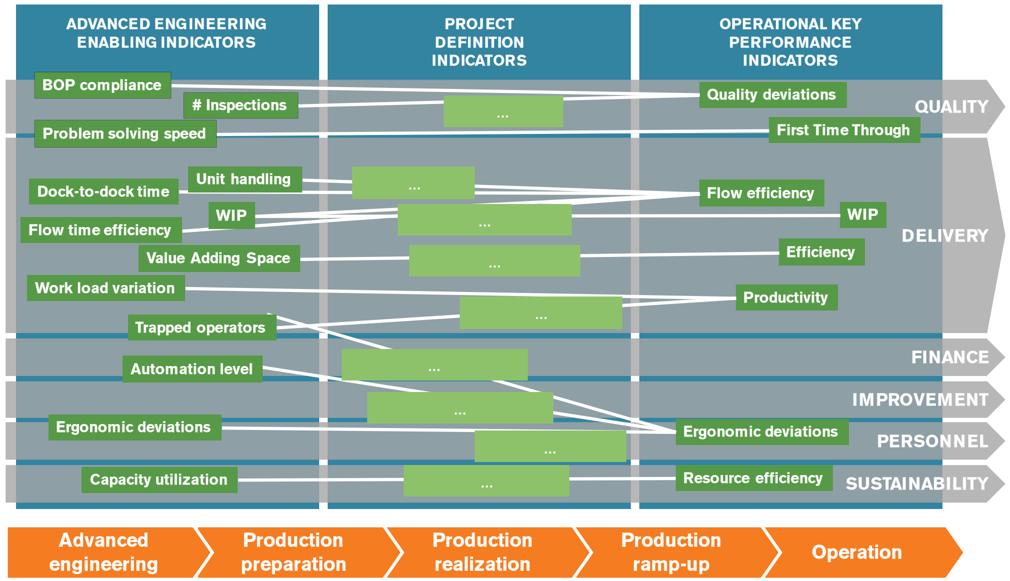
KPIs in early development phases

Performance Indicators are not only essential during operational phases of all the organization's processes. Also during the development phases of both product and production systems, where future performance of the operational order-to-delivery-process is set, KPIs are important to consider. The KPIs designed to monitor progress in early development phases might not have the same scope or purpose as those used during operation, therefore the set of KPIs can and should evolve from the start of a new greenfield project to when operation is running according to plan. In setting up a new plant an early phase activity can be to simulate the layout and capacity of different options. This would require a certain set of KPIs to feed into the simulation software. Considering operational KPIs already in development phases will support future operational top-class performance.

To consider and assess the future outcomes of operational KPIs already in development phases is a challenge, since the amount of data and information is limited. The principle suggested here, is to define areas of "enabling indicators" that can be analyzed or assessed in early phases of product and production development. These early phase KPIs need to be supported by defined means of calculation or assessment. The "enabling indicators" could be operational KPIs or be transformed into operational KPIs as the projects moves from the concept stage into the realization stage and further to the operational stage. For example is OEE not a suitable early phase KPI since no reliable data on performance is available. Instead equipment capacity or "planned runtime per item" is more appropriate, since the equipment provider can contribute with this information.

It is also advisory to perform risk or sensitivity assessments, when there is a lack of reliable data. This will indicate how different parameters influence e.g. costs, and will identify key influential parameters that are important to consider throughout the project. Common areas of interest in early phases relate to e.g. cost analyzes, throughput scenarios or work environment and workplace design principles.

Engineering tools are essential instruments to assess future performance of the product and production system during development stages. Product behaviour is verified by various CAD and FEM tools, producibility is verified by risk analysis, CAM tools and DFA/DFM methods, and production system performance and cost is assessed by simulation and analytical tools. These tools can all be used to guide towards a high performing operational system, in terms of different KPIs.



The figure illustrates how "enabling indicators" were defined by one industrial project partner in early phases of product and process development. These could later be aligned and support later stage "project definition indicators" (not defined in figure) and later also operational KPIs. The principle is to establish this alignment within each KPI area (Quality, Delivery etc) throughout the life cycle of the production system, starting off in Advanced Engineering throughout Production preparation, Production realization, Production ramp-up, and finally Operation.

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