Spacetime boundary for effective energy management

JEITA

<Challenge for energy management>
It is difficult to define a KPI for energy efficiency improvement.

Action
Comparison on equivalent condition

Cause

Complex relationship between the energy consumption and the production volume

<Approach>
Divide the energy management boundary and set KPI for each sub boundaries.

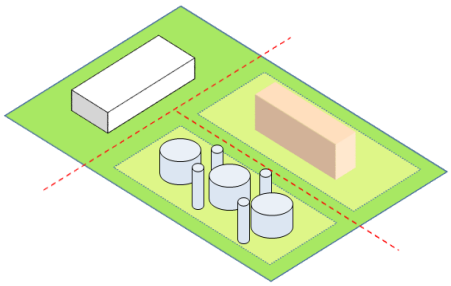
1) Boundary can be defined in both space domain and time domain. The unified boundary is called "spacetime boundary".

2) EMU(Energy Managed Unit) can be extended to the spacetime boundaries.

Note: By comparing on equivalent conditions, the improvement effect is clearly discriminable. To compare on the equivalent condition, the equipment groups of same operation pattern should be collected and managed.

1. Boundary in space domain

Boundary for the energy management in a factory can be defined for entire site, factory, production line, energy intensive equipment depending on the objective of the energy management. This is called boundary in space domain that has a target KPI. Energy consumption of an entire factory and a specific energy consumption of a product are examples of commonly used KPI. Boundary in space domain can be narrowed to concentrate on a specific part that consumes significant energy (SEU : Significant Energy Use) to find an effective point for energy efficiency improvement.

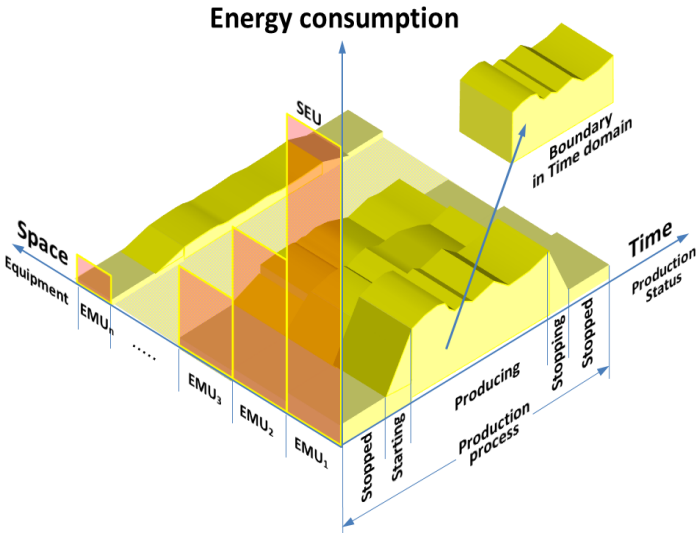


Note: This figure is a conceptual diagram. The physical boundary composed by any equipment groups and the organizational boundary are established as the boundary in space domain.

2. Boundary in time domain

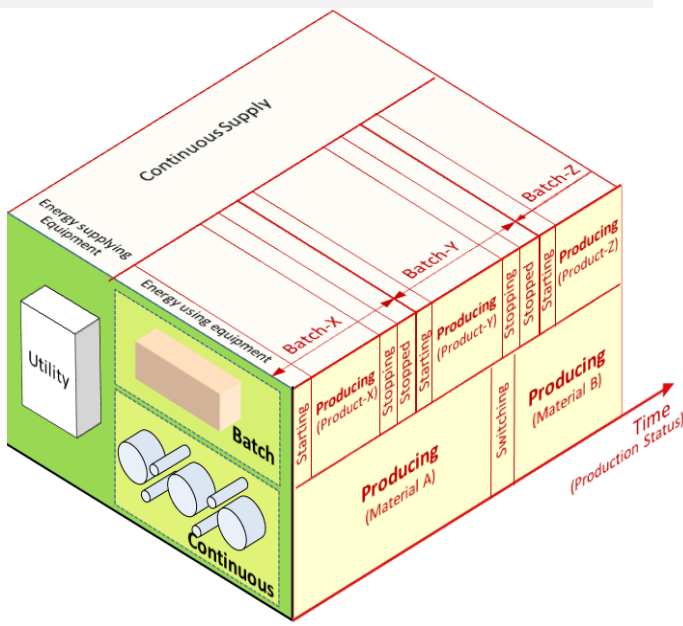
2.1 Energy consumption trend

In the drawing shown below, production process is broken down into such status as Stopped, Starting, Producing and Stopping along the time axis. As the energy consumption characteristic is highly dependent on the status of EMU, it is necessary to manage energy for each status with specific KPIs defined for the status. Production status can be interpreted as a "Boundary in Time domain" in terms of a unit of energy management. Along the space axis, EMUs are represented in order of the quantity of total energy consumption during the production process. Boundary in time domain is defined for every application.



2.2 Spacetime boundary

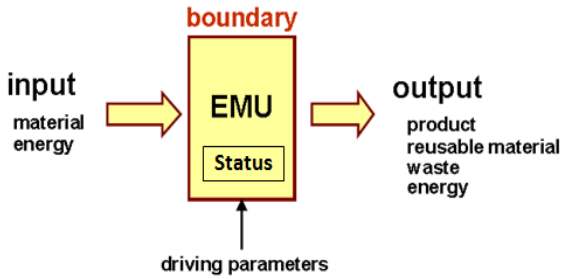
The drawing below shows examples of "Boundary in time domain" of batch and continuous processes. In a batch process, boundaries in time domain are defined for every batch. The brand of product is changed at frequent intervals. When the energy consumption characteristic varies widely by the brand, the production process is designated by the brand. In a continuous process such as oil refinery, same brand is continued for production under the same production conditions for a long term. Even in an oil refinery, the energy consumption characteristic of the process is changed in case of the material (crude oil) change. Boundary in time domain for continuous processes can be defined same as for batch processes.



3. Energy Managed Unit (EMU)

As shown in the figure right hand side, IEC/TR 62837(Edition 1.0 2013-09) "Energy efficiency through automation systems" defines EMU(Energy Managed Unit) as a boundary for energy management. For an EMU in a production process, material and energy are fed into the EMU as input.
Output from the EMU are final product, reusable material, waste and energy. The "driving parameters" include such factors that have considerable effect on the input to output characteristic of EMU such as production volume, start/stop operations of key equipment. The energy consumption characteristics of EMU can change depending on the operation status. So, it becomes necessary to manage energy corresponding to the operation status of EMU that is defined as "EMU status". During the production processes, EMU is operated under the transition of the different "EMU status" that have significant different energy consumption characteristics. "EMU status" can be interpreted as the boundary in time domain for energy management.

Note: Outside temperature is one of the driving parameters to the EMU.

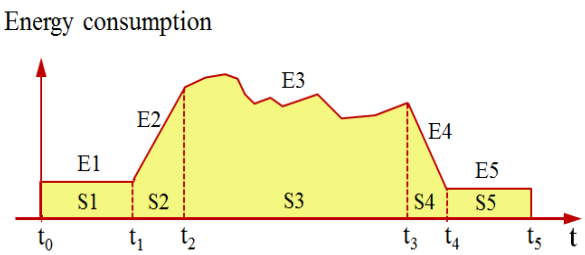


Source：IEC/TR 62837(Edition 1.0 2013-09)
"Energy efficiency through automation systems"

【Note1】Definition of EMU
unit of asset for energy management, identified by an energy related functional partitioning

【Note2】"Status" is added to the original figure.

4. EMU Status



4.1 EMU status and Energy consumption

The figure above shows the relationship between energy consumption and status of EMU. The operation of EMU is done under the operation status from S1 through S5. Ei shows the energy consumption characteristic for Si. (i=1,2,…,5). In [2.1]Boundary in time domain, Stopped, Starting, Producing and Stopping are defined as examples of "EMU status" that have different energy consumption characteristics. Practical production processes have their own specific "EMU status" that should be defined for their effective energy management. The total energy consumption of the production process is the integral of Ei over time of the production. Such status as "Stopped", "Stopping" and "Starting" may consume considerable energy that provides no contribution to the production. In order to improve energy efficiency, it is important to reduce the integral of Ei as well as reducing Ei itself. Time should be minimized for such status that has no contribution to the production. An actual production process may be stopped by an unexpected failure of equipment. This causes loss of energy. It is obvious that establishing a reliable and productive production process should reduce the loss of energy. Operating condition is one of the key factors that give significant effects to EMU. In case of paper and car manufacturing factories, there are several abnormal operating status such as preparation for production, grade change, equipment failure and so on, even during the daily routine production time. The duration of time in a daily production varies for such abnormal status that has different energy consumption characteristics.
It is important to define an appropriate EMU status taking the actual operation situation into account.

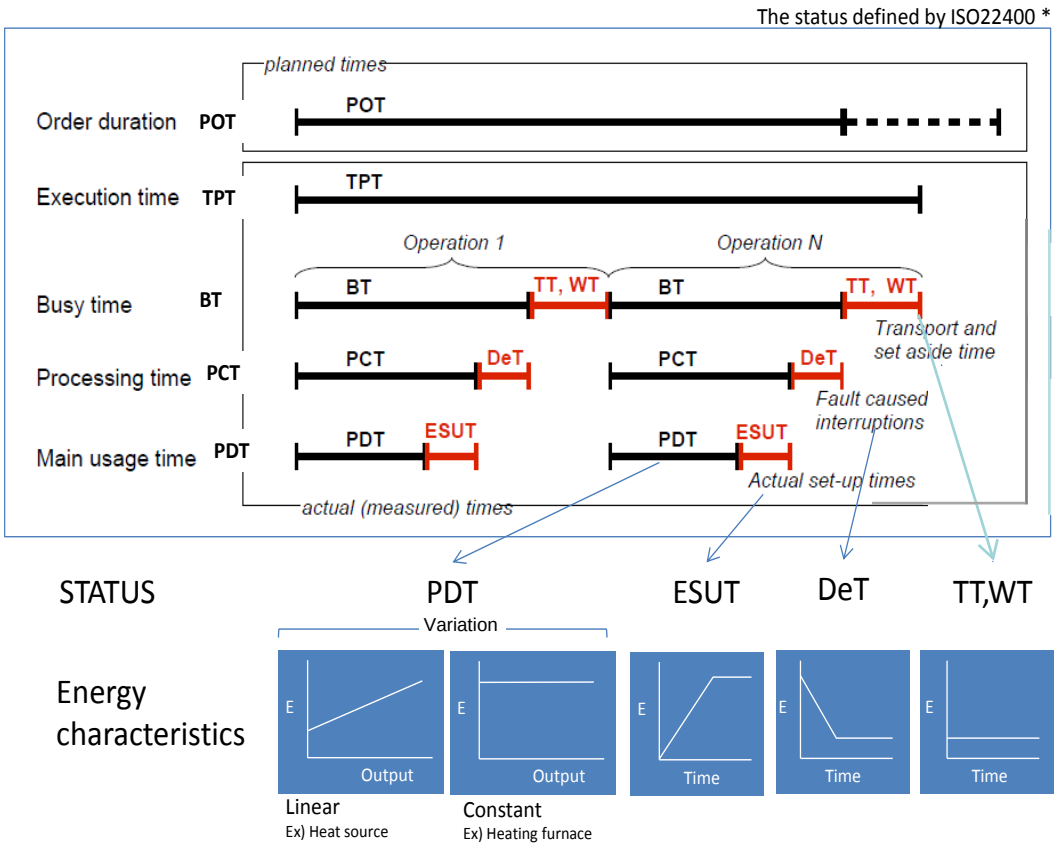
4.2 Equation of Energy and variable

The figure shown below depicts EMU Status and related information. KPI for energy management should be defined based on those information.

EMU status	Number of variables	Variable 1	Variable 2	Equation of Energy and variables
		Name and Unit	Name and unit	
S1 Stopped		-	-	E1=E0
S2 Starting	1	T:Time (min)		t1 < T < t2 E = K1 x T + E0
S3 Producing	2	Q: flow (m^3/ h)	P: pressure (Mpa)	$E = K_0 \times Q \times P + E_0$
S4 Stopping	1	T: Time (min)		t3 < T < t4 E = K2 x T + E2
S5 Stopped	0	-	-	$E5 = E_0$

5. Operation status of equipment during production ---Time model

As shown in the figure below, ISO22400 Manufacturing operations management - Key performance indicators" defines "Time model" for the operating status of production equipment. Execution time in the order duration is broken down to Execution time, Processing time and Main usage time. These times include transport and set aside time, fault caused interruptions and actual setup times that are defined as times of no contribution to the production. The concept of "Boundary in time domain" explained in [2] comes from the concept of "Time model". It provides an interpretation of the unit of production time for operation as a boundary for energy management.
It is necessary to have energy consumption characteristics of every equipment for every time defined below.
The energy consumption characteristics of PDT(Production time/ Main usage time), ESUT(Effective setup time), DeT(Delay time), TT(Transportation time), WT(Wait time/set aside time) are shown in the figure below.
Operation status are necessary to be defined when they have significantly different energy consumption characteristics. It can be practical to use two "times" such as "Main usage time" and "No Production time".



【Definition】

POT(Production order time/ order duration) : Production time schedule that was defined in the production plan.
TPT(Throughput time/ Execution time) : Period of time spent on supplying energy within the boundary and to implement production activity.
BT(Busy time) : Period of time spent on producing one lot. (Lot production time)
PCT(Process time) : Operation time of facilities used for the production activity, regardless of output.
PDT(Production time/ Main usage time) : Period of time spent on production to output products.
ESUT(Effective setup time) : Period of time spent on setting up facilities to execute production.
TT(Transportation time) : Period of time spent on transporting between facilities or from warehouse to designated point.
WT(Wait time/set aside time) : Period of time spent on setting aside in-process item or the stand-by items to be transported to the subsequent process.
DeT(Delay time) : Period of time during which facility is put to stop due to failure of defect.

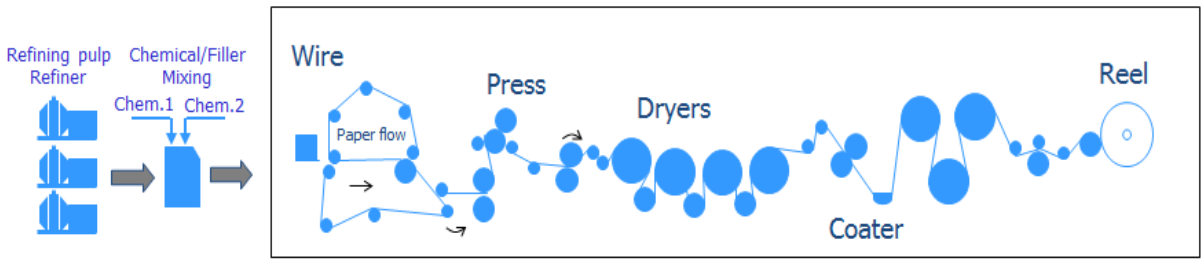
【Correlation formula】

TPT＝Σ（BT＋TT＋WT）
BT ＝PCT＋DeT

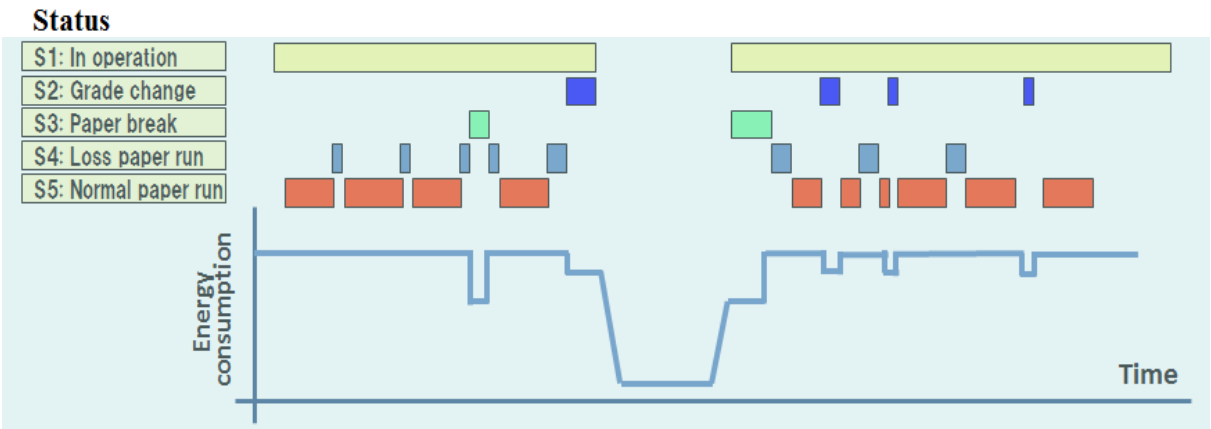
Examples of boundary and status(Paper machine)

The status related to paper machine and paper/coating process of a paper mill factory is introduced. As shown below, using the paper machine structure and the types of available signals, there are 5 major types of status.
(S1)In operation : status that paper machine facilities are in motion for paper production (S2)Grade change : status that paper intermediates (out of specifications) are in process during the paper lot change. (S3)Paper break : status that paper disruption occurs due to some sort of problem, and the paper machine is in operation but not producing paper. (S4)Loss paper run : status that “off specification paper” was produced due to the next process handling forcing the normal paper to be discarded. (S5)Normal paper run：status that paper forwarded to the next process is produced as the normal paper product.

Figure shown at the bottom depicts the energy consumption under the status transition of production. Energy consumption itself during the paper break decreases. However this energy does not give any contribution to the production. This is an example why energy management for status is necessary. In order to evaluate the effect of a measure for energy saving, it is necessary to compare the result in the same operating status transitions.



Signal name / Status	1:Paper machine on	2:Trial run	3:Paper break	4:Good paper	5:Brend change	6:Coating on
	Operation status of raw material transferring pump (ON during operation)	Operator input (ON during trial run)	Photoelectric installed between processes (ON during operation)	Reel rotation counter in operation (ON during operation)	Operator input (ON during change)	Coater ON signal (ON during coating run)
S1:In operation	Yes	No				
S2:Grade change	Yes	No			Yes	
S3:Paper break	Yes	No	Yes		No	
S4:Loss paper run	Yes	No	No	No	No	
S5:Normal paper run	Yes	No	No	Yes	No	Yes



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