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General technical conditions for optimizers

Basics of optimizing

Each operator of an industrial process strives to run the process optimally. This usually happens unconsciously and unsystematically. The aim of these notes is, to help the operator to identify and to formulate the typical objectives of controlling the process.

The usual method of such an action is to describe exactly all the important aims of the process operator in form of an objective function and constraints.

It is important to realize that each production system is subjected to an objective function and one or more constraints by the operator. Another question is whether the operator explicitly knows objective function and constraints or follows them unconsciously. This "unconscious" approach is very common and leads to significant economic losses. These losses result on the one hand from an uneconomical operation, but on the other hand also from the fact that every plant operator in such systems follows a different "strategy".

Rule 1: Every technical process has an objective function and constraints

In fact, there is no controlled process without objective functions and constraints. When they are not known, however, they are nevertheless still unconsciously present. Even a simple controller, a car, and most of our everyday actions are subject to this law.

Example: Car drivers always have an objective function and constraints - even though they are rarely aware of that. They want to reach their destination quickly (objective1), safely (objective 2) and inexpensively (objective 3). It is first necessary to state that the reduction in the probability of an accident (objective2) and the rapid arrival at a destination are contradictory objectives; both can be achieved better the less important objective3 is. This contradiction needs to be resolved by weights of the three goals in the objective function. The constraints consist of the laws of physics, speed limits and other stationary and rolling obstacles on the road.

Recognizing objective functions and constraints for a process and being able to formulate them, one can deliberately optimize a process economically. Without this detailed knowledge, process optimization is not possible, no matter what approach is used.

Besides, by explicitly naming objectives the influence of personal opinions regarding process objectives is reduced. This also prevents the pursuit of harmful goals like reducing the plant operator effort to the detriment of quality and throughput.

Constraints

Operators can usually name their constraints quite clearly. In technical systems, there are always limits of individual parameters which must never be overshot or undershot.

Technical systems cannot operate reliably without the observance of constraints. Constraints always consist of inequalities, defining that a term must not be greater or less than another term. The general form of constraints is as follows:

$$X > Y$$

where the variables can be process variables, real numbers or complex variables.

Examples: If temperature limits are exceeded in sensitive materials, these materials will be destroyed or damaged. Therefore, the temperature must always be held below the critical temperature. If the maximum pressure is not maintained in containers, these may explode. Machines may not exceed certain speeds, otherwise they will be damaged. Reactors or sintering plants may not exceed certain throughputs because otherwise the materials will not have sufficient time to react.

Rule 2: Each process has a certain number of constraints, which can be formulated by one or more inequalities

To identify the current constraints of a process, the best practice is to compile all important process variables which are recorded on a regular basis. Then for each of these, the allowed minimum and maximum are determined.

Looking at composite variables (such as relative energy consumption, efficiency, yield, etc.), minimum and maximum values should be laid down for these calculated values as well.

Objective function

The objective function is more difficult to describe, because the connections to be described here are considerably more complicated. While constraints represent hard limits, which must be met under any circumstances, the objective function is always provided with the premise to be satisfied "as much as possible".

Rule 3: There is no process operating without objective function

An objective function consists of a mathematical function, which includes at least one process variable on which the outcome of this objective function depends. In addition, there is the definition of an objective; it can be minimized or maximized.

Example: An objective function may be very simple, e.g. the fuel consumption per kilometer of a car. This must be minimized while adhering to the constraints. If e.g. this objective function demands to let the car roll to save fuel, this requirement cannot be satisfied when another road user prevents rolling by halting.

Often plant operators are not aware of the fact that they have always followed an unconscious target function. Without a target function, they would not even care whether the plant is running or in downtime. So, at least they want to maximize the amount produced or make production as inexpensive as possible.

Another problem is that operators rarely realize the problems resulting from frequently conflicting goals. Responding to the question of the objective function, they define it as the production of high quality products at lowest prices and in large quantities. However, these three objectives cannot be achieved in full at the same time. Therefore, the operator always has the choice between several objectives. Achieving a goal in perfection means to neglect the other objectives.

Rule 4: Sub-goals of an objective function are usually in contradiction

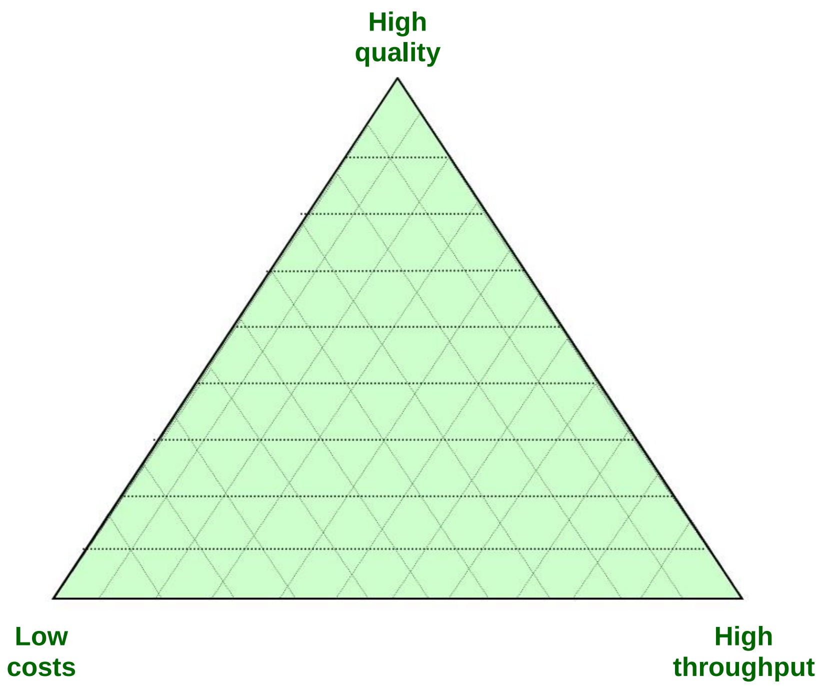
Very often three sub-goals can be defined:

1. High throughput, speed

2. High quality / value / reliability

3. Low price / low cost

The three objectives categories can be presented in the following ternary diagram. One can see in such diagram very well that the perfect attainment of a goal severely limits the other two, that good achievement of two goals means that the third cannot be achieved, and the perfect achievement of all three goals is not possible at all. Ultimately, the operator of a plant has to select a point in this diagram and thereby take into account that the better achievement of one goal restricts the other targets.



A target function is usually formulated in the form of a polynom like:

Z = factor_Q X quality + factor_C X 1 / costs + factor_P X throughput

The factors and parameters have to be scaled to the same specific range of values, e.g. all of them are converted to a range from 0 to 1. The costs are inverted in the above equation, being the only parameter which is supposed to be minimized, while throughput and quality are supposed be maximized.

This objective function is to be maximized in total. The position of the point in the triangle is now controlled via the ratio of the three factors. With all factors equal to 1, the point is in the middle. If the factor of cost and throughput is set to 1 and the one for quality is equal to 0, the point is at the center of the lower edge. So, any technical problem finds an encoding in this format. The three sub-goals are always inherently given, so the three terms can simply be queried and used.

Agreements for manipulable variables

Manipulable variables are the variables which the optimizer can and may change for the process, to achieve its optimization goal. The manipulated variables are to be defined and to be determined and taken into account fully in the consideration of constraints. In particular, it has to be determined in which ranges of values these variables must be maintained and with which increment per unit of time.

Agreements on target functions and constraints

Prior to the final agreement on the specification or requirement specification between the client and ats, both sides agree bindingly on all objective functions and constraints for the optimizer and the manipulated variables.

Before starting up the online implementation of an optimizer, both sides sign a **written document**, in which both bindingly define all manipulated variables, the objective function and constraints. Future changes to the specifications as defined in this document will entitle ats to perform and to charge for additional relevant work.

ats guarantees that objectives and constraints are adhered to as defined in the specifications and the written agreement, as accurate as the measurement accuracy of the measuring systems and the process technology installed allow for.

In particular it is guaranteed that the manipulated variables are set to optimal setpoints, every 5 minutes, within the defined constraints, so that a manual manipulation of the same variables cannot result in a better operation.

These guarantees shall be limited only by safety distances, which however can be influenced by the client using free parameters. One parameter will be made available to the client which can be used to limit the optimization to a safe distance from the constraints in order to have room for adjustments of the operating point and short-term fluctuations of the process caused by such adjustments. This means that critical constraints can be met with certainty. However, the use of these parameters to increase safety and to reduce the optimized operation is restricted to authorized operators only.

Control limits and rules for intervention and manual shutdown of the optimizer

Often there are technical reasons to limit an optimizer that cannot be expressed with constraints. Such reasons may be explosion limits or emissions that are not included in the models, and which require the optimizer to be turned off when they are violated or which limit the effectiveness of the optimizer.

Such rules lead to a restriction of the availability of the optimizer; the client will accept this as not relevant to warranty.

The client declares that they know all these rules and have handed over these to ats in a clear and complete set of instructions or in the form of a consistent operator manual, so that ats can incorporate them into the system.

The client will instruct their operating staff also to act only according to these known and consistent rules and to switch off the optimizer only if it does not comply with these agreed upon and known rules. If an operator switches off the optimizer, although it does not violate any of the rules agreed upon between ats and client in writing, this downtime is at the expense of the client, is not relevant to the availability of the system and therefore not relevant to warranty.

Should client and ats after some time of operation of the optimizer come to the conclusion that the operator rules are not consistent, ats will offer to enhance the rule set and to adapt the system, for an additional charge. For this purpose, ats has new tools for knowledge acquisition available.

Review of the optimizer by control room operators

The client agrees to not comparing the optimizer to an operator for the purposes of performance assessment or acceptance tests, except if the operator follows precise, demonstrable, measureable and clear criteria on which an agreement was made before, in writing.

The evaluation criterion of the optimizer is the objective improvement of the target function in the periods in which the optimizer is in operation compared with periods in which the optimizer is not in operation.