ON EFFECTIVENESS OF THE CONTROL OF PRODUCTION PROCESS

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Abstract The purpose of this paper is to study effectiveness measures of the control of production process. The text refers to research study conducted in some industrial and service organizations in Poland, which was to identify mechanisms of problems in production processes. One of the outputs of the study was classification of some basic sub-mechanisms of the creation of problems. These were: control standards, control data and resources used to control. Some probabilistic measures were established to estimate the effectiveness of control and the probability of problems arising from imperfect control. Findings: effectiveness of control, expressed in terms of the probability of achieving definite goals, is determined by the existence of effective control standards. This, in turn, imposes certain requirements on the data necessary to realise the control scheme and accordingly – on the appropriate material resources. This dependence defines certain order in the set of factors: control standards → control data → control material resources; role of factors: control standards, control data and control material resources turns out to be symmetric. Effectiveness of each of them determines limit for the effectiveness of control. Probability of problem associated with imperfection of control is not smaller than the probability of imperfection of the weakest factor. The paper focuses on some issues that decide on effectiveness of preventing problems in manufacturing processes. The considerations may be useful for organizations that are high sensitive to problems.

Paper type: Research Paper

Published online: 21 April 2011

Keywords: *Management systems, control of production process, effectiveness of control, problem*

1. INTRODUCTION

The classical Ishikawa diagram is a tool of recording ordered causes of a fixed problem. Specific feature that distinguishes this cause-effect diagram are labels that recall typical local causes of problems: human, machine, method, material and environment. When studying general causes of management problems, this set of labels is too general. They can be used to represent mechanisms of creation of problem but some aspects are hard to describe in this way.

In the following text a new set of categories is considered as alternative tool of description of global structure of causes of problem associated with management system. In the set are: resources, standards, and control data. We claim that controllability, observability and availability of appropriate material resources determines effectiveness of control of production process.

1.1. Ishikawa diagram – description of causes of local problem

In this section we focus on Ishikawa diagram as a reference scheme used to describe main components of mechanisms of problems. We consider problems occurring in *manufacturing systems* – systems in which manufacturing takes place. Term *production* is used to denote a general purposeful human activity to make material or immaterial things as well as to deliver services, commercially or not. A word *system* refers to set of elements involved in production and relations that make all them work. Functions of system are performed in various processes. Many of them are mutually dependent because some use effect of another's or some enable proper function of other’s by providing maintenance, by distributing results, controlling etc. (Myszewski, 2009).

A gap between actual and expected state of process/system we call a *problem*. A *mechanism* of problem is a sequence of events, initiated by some event (called the *cause* of the problem), that have the problem as a result. Any problem can have many various mechanisms, which may be initiated by the same cause.

Ishikawa diagram represents local considerations on causes of problem. In the creation of conditions for occurrence of problem, is involved some person who is operating some technical equipment and is processing some material, who is acting programmed by some method. A flow of operation is influenced by environmental conditions. Locality is understood as follows: these factors belong to close neighbourhood of potential perpetrator and consequently may contribute to some mechanism of creating a problem. Question of actual influence of the human factor on the flow of action will be considered later, in the phase of verification of the role of particular factors (Myszewski, 2009).

The diagram plays an important role as a tool of recording the potential causes of the problem. A graphic representation of relations between particular causes helps better understand their importance. This way of representing structure of problem is intuitive. It enables discussion with various people whose opinion could be of some value. It can be stored and used in future when problem comes again. May be useful in formulating new hypotheses on causes and in verifying significance of possible causes already considered and so on.

It represents also some very important empirical fact about causes of the problem observed in the organisation. They can be complex. Various components of the system may contribute to occurrence of problem. One cannot focus too much on one thread only. The diagram represents hypotheses on how the problem might arise. The next step is to verify the contribution of specific factors to the creation of the very problem.

1.2. Categories that define causes of management problems

Problems such as machine failures or nonconformities of product can be considered as local ones. However, those local problems may have global roots, that may be located far away from the place where problem was noticed.

It would be too trivial to say that in creating problem involved are people, technical equipment or material. From the point of view of the management of the whole organisation, more fruitful would be answer why the resources used by organisation fail to meet requirements, and how to prevent such failure in the future. Analogously we generalise other categories from Ishikawa diagram.

Category “method” we substitute by more general category “control standard”. We use word *standard* to denote some pattern of system or process. Examples of standards are various operational instructions, specifications of technology and general policies used by management of organisation. They are established in order to reduce variability in processes/systems. They represent operational knowledge of organisation. They are programming people when they use resources and when they control functions of operation (Myszewski, 2009).

In local considerations a category “environment” stands for all influences that originate from outside the workplace. However in global considerations the meaning of environment is slightly different. It is management’s task is to assure effectiveness of basic functions of organisation even in the presence of disturbances. Conditions of functioning of organisations are full of chaotic phenomena and therefore system/process should be robust against them. That is why the category environment, in management consideration, should be replaced by category that describes organisations ability to control its main processes. These conditions recalled as controllability and observability of management system (see the Section 2).

By rearrangement and generalisation of categories from Ishikawa diagram we select the following classes of mechanisms of problems in manufacturing system:

- Resources: material resources used to achieve a control objective
- Control data: the data that are necessary to achieve control objective

- Control standards: standards that are to used to achieve a definite control objective. Among them are standards that instruct how to use other standards or how to use and maintain material resources and data.

Effectiveness of use of elements of the above categories to control production process is referred to as process' controllability and observability.

2. CONTROL OF THE PROCESS

Production systems can be viewed as complex control systems. The objective of the production system is to assure effectiveness of production process. In effect the process provides products that meet specification requirements in optimal way. The optimality may mean that cost of production is minimal or the use of resources in the process is minimal or delivery of production batches is precisely on time. To assure that these objectives are achieved, necessary is control function. The *control* is such an influence exerted on control object, using the input signals, that the output signals can reach the desired value (Kaczorek, 1981).

A *control system* is a system, in which the process of control takes place. Apart from some very simple cases, description of real system (in particular, of production system) in terms of pure "control object" and "controller" is not easy, because of complexity of structure of the system. For some details of this issue see (Myszewski, 2010).

2.1. Closed-loop control system

There are many objectives formulated for the production system:

- to provide products in accordance with quality and quantity specification, and timely
- to improve effectiveness and efficiency: to prevent losses and failures, to prevent accidents, to improve quality, productivity, to enhance flexibility of production and customer service.

In the structure of organisation there are special entities concerned with particular objectives. They conduct control actions directed to ensure that the objectives are achieved.

The data coming from the production process is analysed and, in response, the control signal is sent to the process. The sequence: "data" → "control signal" forms a loop which is called a "feedback". The *feedback* is the influence of output signal of the process on its reference input signal. It consists in receiving, by the control system, the information about effects of control and in using this information to modify the input signal. A *closed-loop control* is a scheme of control, which includes feedback to generate input signal on a base of output signal. Given any fixed reference signal, when deviation of the output signal from the reference one is detected, a control signal is generated to eliminate the deviation. Such a control scheme represents “negative feedback”. *Negative* feedback is a scheme of control with feedback loop, for which any deviation from reference signal generates control signal that is to change the output signal in the opposite direction. The effect is that the changes of output signal are attenuated.

Control systems with negative feedback

- are able to stabilise the process when some disturbances occurred
- can reduce sensitivity to parameter variations
- can improve ability to track the reference signal.

2.2. Open-loop control system

There are some internal control functions incorporated in the production process, and their objective is also to ensure that the process achieves objectives. Standards that are used in the production process define specific scheme of control. The control scheme which does not make use of process’ output signal is called *open loop control*. An open-loop control is a scheme of control, which computes control input signal using only the current state and model of the process.

Open loop control systems

- are relatively simple and inexpensive in realisation
- are effective, when there is no substantial disturbances.

Set of standards used in the process provides means of open-loop control. Their influence consists in instructing people how to perform various operations.

Effectiveness of this control depends on

- self-discipline of people who have to obey standards
- degree to which they have mastered
- quality of standards:
  – level of difficulty
  – sensitiveness to disturbances
  – properties of disturbances.

2.3. State space

Internal state of the system is a collection of system's variables values, that completely describe the system at any given time. Totality of states is called a *state space*.

In production process, system variables are (among others) parameters that describe dynamics of the process, parameters of the resources in the process and parameters of close surrounding. Number of items that define system’s state variables is called state space *dimension*. In chemical or metallurgical processes actual number of the variables may be infinite. Even in much simpler cases, as for example in assembling processes, number of state variables could be arbitrary big. Each component of the process contributes to description of dynamics. Technical equipment, operators, parts are independent from each other. Each can be considered as multidimensional system. Exact description of such systems, though not impossible, would have minor practical importance, because of its complexity.

We use the word *model* to denote representation of some system/process by another system/process, which is more easy to handle.

3. CONTROLABILITY AND OBSERVABILITY

Characteristics of the control of production process can be characterised in terms of

- ability to achieve certain goals or
- ability to react promptly on a change of the reference signal or
- sensitivity with respect to some external disturbances.

From the viewpoint of the production process, the above issues are closely associated with ability to implement new products, with the flexibility of the process and with ability to function in a chaotic environment.

3.1. Controllability

Controllability is the ability of an external input to move the internal state of a system from any initial state to any other final state in a finite time interval (Ogata, 1997). We say that a production process is *locally controllable*, if given any initial state and any sufficiently close final state of the process, there exists a control algorithm that instructs how to transform initial state into a state that is close enough to the final state in finite time interval, with acceptable high probability, provided all necessary data and resources are accessible.

Due to randomness of main process and of control process it may happen that the control algorithm will transform the initial state into a state far from the expected final state or that the transformation may take more time than expected. In case of controllable process the probability of such ineffectiveness is acceptably low. Attribute “local” of controllability is associated with practical assumption about system: task that are assigned to production system are typical – specification parameters are “similar” as similar are products from the same product family.

If the (management) system is (locally) controllable then:

- there is sufficiently broad set of effective control algorithms
- there is sufficiently broad freedom of choice among various variants of decisions
- there are established effective rules of decision making
- there are established requirements for necessary data

- there is established effective two-directional communication between all places that require data and relevant data sources
- there are established effective rules of identifying requirements on resources necessary to implement decision made.

The local controllability represents ability of the control system, composed of closed-loop and open-loop schemes, to achieve local goals with acceptable accuracy in acceptable time. The condition is that there are appropriate resources associated with production and appropriate data.

3.2. Observability

Observability is a measure for how well internal states of a system can be inferred by knowledge of its external outputs (Ogata, 1997). We say that the production process is *locally observable*, if given any initial and any sufficiently close final state of the process, there can be provided all data necessary to transform initial state into a state that is close enough to the final state in finite time interval, with acceptable high probability, provided all necessary resources are accessible.

If the system is (locally) observable then

- there are established requirements for data used in all relevant places in the system
- there are identified characteristics necessary to be observed in order to provide data
- observation of the above characteristics are performed with satisfactory uncertainty
- results of observation are analysed appropriately to obtain information necessary to control
- data and results of analysis are accessible with all data necessary to assure traceability.

The local observability represents ability of the control system to have all information that is necessary to achieve local goals with acceptable accuracy in acceptable time. The condition is that there are appropriate resources associated with production.

3.3. Observability and controllability

System is locally controllable and observable, if given any initial state and any sufficiently close final state, there exists control algorithm that shows how to transform initial state into a state that is close enough to the final state, in finite time interval, with acceptable high probability, provided all necessary resources are accessible.

Any organisational unit of the manufacturing system is subject to control performed in both

- open loop control scheme:
  – these are all actions performed within the unit to assure that the result is conforming requirements/expectations
  – they are based on standards used in the unit that give instruction how to perform particular operations
  – the control may involve closed loop control schemes used to control component phases or sub-units in the unit;
- closed loop control scheme:
  – these are control loops established to monitor and inspect operation of the unit by superior entities.

Apart from formal control actions defined by system standards, there are also informal checks performed by particular people in organisation. These are:

- individual control done by operators on their work places. This kind of actions can be considered as manifestation of their professionalism
- random checks done by chance, that are not part of the job. This is a way they manifest their involvement in affairs of organisation.

The local controllability and observability represents ability of the control system, composed of closed-loop and open-loop schemes, to achieve local goals with acceptable accuracy in acceptable time. The condition is that there are appropriate resources associated with production.

4. P-MEASURES OF EFFECTIVENESS OF CONTROL

p-*measure* of *local controllability* = the probability that, for any two sufficiently close states of the system there exists an algorithm to transform one into the another in a definite time, provided necessary data and material resources are available.

Denote:

A= “given any two sufficiently close states of system there exists an algorithm (standard) how to transform one onto the another in a definite time”,

D=”all necessary control data are available”,

R=”all necessary material resources to control are available”.

Then the p-measure of local controllability = $P(A|D\&R)$, where symbol P denotes probability measure, $D\&R$ denotes conjugation of assertions D and R ($D\&R$ is true if and only if both D and R are true), $P(A|D\&R)$ denotes conditional probability of assertion A if condition $D\&R$ is true
$(P(A|D\&R)=P(A\&(D\&R))/P(D\&R))$

Remarks: Local controllability corresponds to typical task to keep process parameters within tolerance limits, or to recover the appropriate state after some failure. Lack of controllability may cause a problem. Process of establishing the control algorithm is controlled by some algorithm and involves some resources and data. Their ineffectiveness may cause imperfect controllability.

p-*measure* of *local observability* = the probability that data necessary to control is available, provided available are all material resources necessary to control.

By use of the symbols introduced above one can express the p-measure of the local observability by the symbol $P(D|R)$.

Remarks: Local observability corresponds to situations where some feedback is necessary to establish effective control. Source of data may be inspection done according to the control plan. Data may also be provided by people of the process, who are reporting their observations done beyond formal duties. Specification of necessary data and way of their usage is determined by algorithms of control.

Process of providing data involves material resources and algorithms. The effectiveness of the process depends on its controllability and observability as well as on availability of the necessary resources.

p-*measure* of *availability of definite resources* = the probability that the resources are available in definite conditions (time, place). It can be represented by symbol $P(R)$.

Remarks: The p-measure of availability of resources reflects level of effectiveness of measures taken to provide resources. The failures can be explained by the imperfection of controllability and observability of the process of providing material resources as well as by the imperfection of resources used in this process.

p-*measure* of *effectiveness of control* = the probability that, given any two sufficiently close states of the system, there exists an algorithm to transform one into the another in a definite time and all necessary control resources and data are available. The p-measure of effectiveness of control can be expressed by symbol $P(A\&D\&R)$

Assertions:

a) p-measure of effectiveness of control is a product of p-measures of the controllability, observability and availability of resources:
$P(A\&D\&R)=P(A|D\&R)P(D|R)P(R)$

b) p-measure of effectiveness of control is not greater than minimal value among p-measures of factors: controllability, observability and availability of resources:
$P(A\&D\&R) \le min\{P(A|D\&R); P(D|R); P(R)\}$

c) Denote $B=(A\&D\&R)'$ a negation of assertion $A\&D\&R$, then $P(B) \ge max\{P(A'); P(D'); P(R')\}$

d) with the notation as above: $P(B) \ge max\{P(A'|D\&R); P(D'|R); P(R')\}$

Sketch of the proof of a:

By a basic rule of the probability calculus, the right hand side can be represented as a product

$P(A\&D\&R)=P(A|D\&R)P(D\&R)=P(A|D\&R)P(D|R)P(R)$

Sketch of the proof of b:

Each of factors is real number from the interval [0,1], therefore

$P(A\&D\&R) \le min\{P(A|D\&R); P(D|R); P(R)\}$.

Sketch of the proof c:

$P(B)=P((A\&D\&R)')=P(A' \text{ or } (D\&R)')=P(A')+P((D\&R)')-P(A'\&(D\&R)')$

$=P(A')+P(D\&R)')-P(A'|(D\&R)')P((D\&R)')$

$=P(A')+P((D\&R)')\{1-P(A'|(D\&R)')\} = P(A')+P(A|(D\&R)')$

$=P(A')+P((D\&R)'|A)P(A)/P((D\&R)')$

$=P(A')+P(A\&(D\&R)')/P((D\&R)')\ge P(A')+P(A\&(D\&R)')$

Thus

$P(B) \ge max\{P(A'); P(A\&(D\&R)')\} = max\{P(A'); P(A\&(D' \text{ or } R'))\} \ge P(A')$

Because role of symbols A, R and D is symmetric, the above inequality can be rewritten formally as follows:

$P(B) \ge max\{P(R'); P(R\&(A' \text{ or } D'))\} \ge P(R')$

$P(B) \ge max\{P(D'); P(D\&(A' \text{ or } R'))\} \ge P(D')$

Thus

$P(B) \ge max\{P(A'); P(D'); P(R')\}$

Sketch of the proof d:

It was already proved in point b, that $P(A\&D\&R) \le min\{P(A|D\&R); P(D|R); P(R)\}$. This is equivalent to the inequality: $1-P(B) \le min\{1-P(A'|D\&R); 1-P(D'|R); 1-P(R')\}$. By multiplying both sides by -1 and next by adding +1 to both sides, we get the inequality.

Conclusion:

- The effectiveness of control is not greater than the least measure of effective provision of control standards, control data and material resources necessary to control the system.
- The probability of problem in the system resulting from ineffective control is not less then the worse assessment of ineffectiveness of provision of control standards, control data and material resources necessary to control the system.
- Therefore none of the aspects of control: providing appropriate control standard, control data or control resources cannot be considered as less important than others.

5. CONCLUSION

Effective control of production process is a state of management system which consists in achieving control objectives with accepted probability. Any failure to achieve a control objective is example of problem. Mechanisms of the generation of problem involve imperfection of control standards, control data and material resources used to control.

Effectiveness of control is limited by the effectiveness of controllability and observability and by effectiveness of material resources used to control (including people). The probability of problem is not less than worse assessment of ineffectiveness of the control algorithm, of provision of control data and of material resources used to control (including people).

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BIOGRAPHICAL NOTES

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