Methodological aspects of systemic designing of foundry plants

R. Wrona*, A. Stawowy, A. Macioł

* Faculty of Foundry Engineering, AGH University of Science and Technology, Reymonta 23, 30-059 Krakow, Poland
b Faculty of Management, AGH University of Science and Technology, Gramatyka 10, 30-067 Krakow, Poland

Abstract

An approach is attempted to systematise the systemic research. A set of hypotheses are formulated, defining how a conceptual design of a foundry plant should be developed and improved when it is investigated as a system. The methodology aims to eliminate the particular approach to design to be replaced by integral design. The need of integral design seems a logical consequence of a transition from task-oriented design to situational design. The methodology outlined here offers an innovative and modern approach to engineering design, particularly in foundry plant design.

Keywords: Foundry plant design; System; Systemic approach

1. Rationale of the systemic approach

The backgrounds of systemic approach stem from the concept of a system in the context of development of scientific thought, it should not be treated as just a new technical procedure. The key aspect of the systemic approach is defined as the order subjected to creative thought and rational actions. An attempt to define this ‘order’ goes back to Aristotle, and his holistic and teleological concepts. The statement made by Aristotle: ‘the whole means more than the sum total of its parts’, defines the fundamental problem of the systemic approach, which still remains a current issue. The problems covered by the word “system” did not appear yesterday and are not restricted to current issues addressed by mathematics, engineering and technology. They should be rather understood as present-day formulation of problems which became known years ago, which were discussed using the language of those times as science was not yet developed to handle them properly. In the late 20th century von Bertalanffy [1], a creator of a new principle of learning the world referring to natural organisms, formulated the concept whereby:

- an organism is a dynamic phenomenon, changing in processes
- an organism is an active system, its behaviour takes into account probabilistic relationships

This view, as the basis of research, is referred to as organisinal biology and as an attempt to explain things is known as the systemic theory of organisms. This program is regarded as novelty in literature in biology and provided the backgrounds for the general theory of systems. When the term ‘organism’ is replaced by ‘an organised entity’, such as social groups, technical facilities, manufacturing processes, factories, the quoted program becomes a program in the theory of systems.

The Aristotle’s statement whereby ‘the whole means more than the sum total of its parts’ was then developed to extend to “properties and means of acting on higher levels of the organisation cannot be explained by summing up the properties and means of action of their constituents, investigated separately”. However, when the set of components and the interrelationships between them is known, the higher levels of an organisation can be highlighted by their analysing their constituents [1]. In other words, to understand an organised entirety, it is required that its components and the interactions holding between them should be known.
2. Systematising the systemic studies

In works on systemic studies the tendency is revealed to distinguish three basic areas: science, technology and philosophy [2].

In the area of science two aspects are of key importance, though their applications separable. In the first meaning science denotes the knowledge about systems, implying research. The other aspect involves the general theory of systems in various branches of science, encompassing the principles relating to all or clearly defined classes of systems. A system is thought to be a model of general character, a conceptual analogy of some universal features shared by observed objects and plants.

The second area of the general theory of systems involves technology, often referred to as systemic technology, covering fundamental aspects of present-day technologies and societies, both in terms of hardware-control technology, automatic control, IT and the conceptual level (software application of systemic concepts and theories to the environmental, technical, economic and social problems). No matter what scientific interpretation of these problems, these are without any doubts systemic problems involving the interactions between large numbers of variables.

Philosophy of systems means re-orientation of scientific thought, as a consequence of introduction of ‘systems’ as an new paradigm. It is an opposite of an analytical, mechanistic and linear-causative paradigm from classical science. It means the way of perceiving things which are often neglected and in this context it becomes a methodological aspect, allowing for formulating the statements characterising material, IT and conceptual systems.

The advantages of systemic analysis are revealed mostly in formulation of problems rather than searching for solutions of the existing ones. These are real advantages, since problem formulation heralds the beginnings of every kind of creative activity. Creative activity leads to the development of an abstract, then logical-structural system with its contents.

3. Principles of systemic design

Adoption of the systemic approach results in the work being targeted at integrated design and development of adequate procedures. It is important to realise that a systemic concept does not lead to the set of principles or statements, but becomes a point of view in design. The design process involves the analysis of major interactions within a system, followed by inferring based on the underlying model of the system. Generally, the systemic concept is based on several principles:

- system complexity has to be taken into account, in other words elements of the systems are thought to be ordered and subjected to changes in time,
- assuming the integral characters of each tested element within an organisation, understood as the system of interacting and interrelating elements, which leads to the concept of an whole (integral) entity,
- recognising the hierarchy, an object is viewed as a set of hierarchically arranged formations on various levels of complexity. All entities on the lower level are referred to as subsystems, those on the upper levels – super-systems.

- additional property - ability to incorporate new elements in the structure of an analysed system and complementing this structure, which changes the status of the system operation. This principle is of key importance when designing the reconstruction of foundry plants

- conversion, meaning the ability of a system to change and transform, in order to function the system absorbs the new components from the surroundings, aiming at a certain goal, which is perceived as the most advantageous state

Combining those principles of systemic approach with the preplanned research procedure leads to the formulation of systemic methods.

Of particular importance are:

a) method of system analysis, involving the mapping of the fragment of reality regarded as the set of objects and relationships making up a whole. The whole entirety is treated as a system,

b) method of structural system model, whereby a simplified model of a structure of the analysed entirety is created.

Development of the model requires that three basic rules are considered:

- organised complexity,
- organisational integrity,
- hierarchic structure of systems making up the whole,

c) method of functioning of the system model, involving the analysis of functioning of the given object (as a system) and presentation of a simplified model (a formula or algorithm) of functioning based on additive and conversion principles,

d) system retrospection method involving the backward analysis of various stages of the system and its structure. This approach might explain the path of system development to date and to reveal certain regularities in system development.

The extended scope of applications of system–based methods leads to the development of systemic methodology, its main tool being the system’s model. Underlying the system operation and its components are relationships between input and output parameters and feedback functions identifying inputs and outputs, which involves the flows of mass (materials, products, tools), energy (flows in installations, pipes, conduits), information and the flows of human factors. The feedback principle implies that a system is an abstract term and as such underlies the operation of a real plant, for example a foundry plant. Production systems are so complex and intricate that nearly independent functional elements can be easily distinguished. In practical applications, even for most complex systems a three-level structure is sufficient: system-subsystem-system element. Normally, subsystems are thematic or functional groups of independent, homogeneous elements. The condition for sufficient independence of any part of the system is the scope of functions it has to be play within the given technology, stages of manufacturing processes, the circulation of information, the life cycles and the basic management functions. For each functionally separated part of the system one has to formulate the scope, task, requirements and assessment criteria. Thus a set of design tasks is formulated for the whole system and its all constituents.
4. Objectives of development of a design model of a foundry plant

The foundry plant design involves the interrelations of its elements in space and time, which is equivalent to development of structures in the statistic and dynamic context. Independent analysis of particular structures is seen as a methodological error and does not offer the right direction for optimisation. The influence of structural solutions on system efficiency (foundry plant) and its importance at the early stages of plant construction implies that a specified sequence is required while developing these structures.

Broadly speaking, underlying the design process is the manufacturing process of castings, this is not strictly true as the manufacturing process is designed already at the stage of plant design. It is reasonable to state that a casting structure is given as an input (beginning of the design process) and get the organisation of the foundry plant at the output, providing the required output of castings at specified cost levels. To achieve this, it is required that:

– production schedule and the technological option should be selected,
– subsystems should be specified accordingly (division into system elements and their interactions),
– identification of subsystems through linking the production process, system parameters and decision points,
– design of system development, linking the system to its surroundings,
– design of the management and control functions, the hierarchy of system elements is established on the basis of decision plans.

The selection of a technological process depends on the set of castings assortment, making up the production program of the foundry plant. As a rule, the production program covers the castings with various structural and technological properties. To introduce some order, castings are classified accordingly and for each category the set of applicable technologies of defined [3].

In the next stage subsystems are found that group structural components required to performed the technological processes. The distinctive feature of thus distinguished subsystems is that their interactions result from technological processes. The less complex component, the easier its physical or mathematical description.

A formal description of a system should contain variables describing the state of the system at specified moments of time. The complete set of characteristic variables makes up the phase space of the system. The system of a foundry plant designed for the service life $T$ comprises subsystems $p$ making up the set $P_p$.

$$P_p = \{ p_1, p_2, \ldots, p_n \}$$

(1)

The number of subsystems depends on the scope of the enterprise and might become $i=1,2,3,\ldots,n$. Each subsystem $p$ contains elements making up separate subsets $p_r$, whose number depends on the number of subsystems and the function the subsystems and system components ought to perform. Accordingly, within the set $P_m$ $m$ subsets $p_r$ are distinguished, forming the separate set $P_m$:

$$P_m = \{ p_{r1}, p_{r2}, \ldots, p_{rm} \}$$

(2)

Further division of elements in particular subsystems yields the elementary components, such as machines, installations. Elements distinguished from the subsystems have different properties, depending on the type of equipment required for the technological process. In order to describe those properties it is required that technical specification $W_m$ be provided for each element. The technical specification forms the set of individual features of a given element.

Foundry plant (system) operation in the time $T$ requires that its components be incorporated for the time interval $\Delta t$. That means that in the time interval $\Delta t$ the production process will involve elements belonging to one of the subsets $p_r$, making up the set $P_m$. The subsystem $p$ in the time interval $\Delta t$ is in the state $Z_p$. The state of the system – a foundry plant in time is expressed as:

$$Z_p = \{ Z_{p1}, Z_{p2}, \ldots, Z_{pm} \}$$

(3)

The projected goal to be achieved and the constraints impact on the operation of subsystems. This can be expressed by a functional relationship $f(T)$ which takes into account the key features of the technological process and the available equipment. The full definition of the behaviour of the system in time is given by a set of functions governing the subsequent phases of the technological process.

$$F(T) = \{ f(T)Z_{p1}, f(T)Z_{p2}, \ldots, f(T)Z_{pm} \}$$

(4)

where: $F(T)$ – set of functions which under the assumed conditions and assumptions determines the probable state of the system in the time interval $T$.

Decision points are determined knowing the details of the production process, with the defined inputs and outputs to the subsystems and the details associated with technological operations. This reasoning is shown schematically in Figure 1.

Fig 1. Model of dynamic design of structures in the system of a foundry plant
It is readily apparent that the analysis and design of structures is based on variations of inputs to the subsystems and the whole system of the foundry plant, which in turn allows the production, spatial and organisation structures to be determined.

Other activities are aimed to ensure the required flexibility and resilience of the system, of particular importance is the Programming description, underlying the design procedure (Figure 2).

At one stage of the design procedure the production capacity of particular system elements are ensured, such that their availability whilst in service should be larger than the projected loading during the manufacturing process. In the conditions of projected disturbances, that does not involve simple arithmetic summing up the time consumption at particular workplaces, instead we are faced with an intricate design methodology. Each subsystem distinguishable from the system is determined by:
- task loading as a consequence of the production schedule,
- ordering and interactions with other subsystems,
- scheduling requirements, the operation of such subsystem is controlled by its internal effectiveness and input and output relation (Figure 3).

Internal effectiveness is associated with reliability of the basic equipment, tools and means of transport. On account of the form of the dynamic model, the efficiency of technological, transport and human systems is of major importance.

The key requirement in the programming description is to ensure the desired level of availability of the foundry plant system through the technical and organisational integration of subsystems and elements making up the entire foundry plant.

5. Potentials and constraints of systemic approach

The advantages of the systemic approach can be recapitulated as follows:

a) the basic goal is to work out or select the method enabling us to solve the problem,
b) in terms of methodology, elementary operations are identified that are performed in complex plants,
c) at the first stage the relationship is analysed between the components and the environment. That affords us the means to seek solutions without analysing the technological units at that stage,
d) depending on the procedure, the object might be formalised mathematically and logically,
e) the main goal involves the optimisation of interactions and their network, which underlies the rational identification of system’s properties.

Like every other theory, the systemic approach uses a set of notions and criteria. It usually involves modelling, classification and formalisation. It is a method involving synthesis and analysis, which facilitates the identification and finding of hitherto unknown relations and interactions. It allows for identification of STATE before OPERATION and after operation, without prejudicing how the CHANGE of STATE is to be accomplished. The system approach underlies the sequencing of any creative action, which is illustrated by the following sequence: NEED – SYSTEM – CONSTRUCTION (material object). It recognises the need to use several models of problems and requires that the methods of action be chosen individually. This is the key issue: objectivity of the systemic approach to design.

Acknowledgements

This work is supported by the MN from the resources assigned for scientific researches in years 2006 – 2009.

References