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General Technology (Elements of Theory and Application)

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Abstract

The goal of general technology as a technical science is to analyze and determine the structure and parameters of technological systems. In order to achieve this goal, it is particularly important to use quantitative methods in addition to qualitative methods. Starting from the central position of civil engineering within the technical sciences, the special role of construction technology within general technology is also presented. Quantitative methods include above all the mathematical modelling of technological systems. The mathematical models are based on balance equations in the form of material, energy, and momentum balances. Many publications and inventories on general technology neglect the quantitative methods that are of particular importance for practical engineering. Of particular importance for the further development and application of general technology are the relations with ergonomics and communication science. This involves a contribution to the design of a new world of work, which consists above all in the coordinated development and application of a variety of innovation methods and in the first-time creation of optimization algorithms for increasing the effectiveness of work processes. The methods of general technology for the analysis, modelling and optimization of technological processes and plants have been or are used in the realization of the following projects:

- Production of diesel from organic waste and residues.
- Conversion of waste heat into electricity.
- Mobile and energy self-sufficient technological systems for waste processing.
- Transport, handling, and storage processes in construction technology.
- Increasing the effectiveness of biogas plants by methanisation of biogas.

Keywords: Methods of Innovation; Life Cycle of a Technical System; Mathematical Modelling; Universal Technology; Optimization Algorithms; Waste Heat; Methanizing Biogas; Materials Economy; Material Balance; Energy Balance; Momentum Balance; Heat Mobility; Heat Transfer Area; Heat Transfer Coefficient; Kinetic Constants; Enthalpy of Reaction; Geometric Dimensions

Summary

The goal of general technology as a technical science is to analyze and determine the structure and parameters of technological systems. In order to achieve this goal, it is particularly important to use quantitative methods in addition to qualitative methods. Based on the central position of civil engineering within the technical sciences, the special role of construction technology within general technology is also presented. Quantitative methods include, above all, the mathematical modeling of technological systems. The mathematical models are based on balance equations in the form of material, energy and momentum balances. Many publications and inventories on general technology neglect these quantitative methods, which are of particular importance for practical engineering activities. In addition to the results of the "General Technology" working group of the Leibniz Society of Sciences and Humanities, previously unnoticed sources from teaching, research and practice are analyzed and included in our considerations. Of particular importance for the further development and application of general technology are the relationships with ergonomics and communication science. The aim is to contribute to the design of a new world of work, which consists primarily in the coordinated development and application of a variety of innovation methods and in the initial creation of optimization algorithms to increase the effectiveness of work processes. The methods of general technology for the analysis, modeling and optimization of technological processes and equipment have been or are used in the implementation of the following projects:

- Production of diesel from organic waste and residues.
- Conversion of waste heat into electricity.
- Mobile and self-powered technological systems for waste processing.
- Transport, transshipment and storage processes in construction technology.
- Increasing the effectiveness of biogas plants by methanizing biogas.

Introduction

The objectives of general technology, which can also be referred to as universal technology, can be summarized as follows:

- analysis and determination of the structure and parameters of technological systems throughout the life cycle of a technical system (design, implementation, operation, reconstruction, disposal) using qualitative and quantitative methods
- analysis of the feasibility (methodological, personnel, economic) of a technological system.
- coordination of content between the technical sciences, the natural sciences and the social sciences.
- Role as a driving force in the development of science and elaboration of recommendations for the application of innovative methods.

Based on the central position of civil engineering within the technical sciences, the special role of construction technology within general technology is also presented. In describing the role of general technology in the context of the development of science, the relationships with communication science and labor science are described. Quantitative methods include, first of all, mathematical modeling of technological systems, which will be discussed in the next section. Many publications and inventories on general technology neglect the quantitative methods that are of particular importance for practical engineering activities. In this context, reference should be made to the book "Analysis and Control of Processes in the Materials Economy", which was published in 1971 by Akademie-Verlag and Deutscher Verlag für Grunds to technologies. The editor is Klaus Hartmann, a member of the Leibniz Society. In terms of content, this book is dedicated to the system-theoretical analysis of technological systems (cf. Hartmann 1971). Another publication in this field is the book "Knowledge-based Systems in Automation Technology", which deals primarily with the dynamics of technological systems in the life cycle of these systems (cf. Balzer et al. 1991).

With regard to general technology, the colloquia on general technology at the Technical University of Leipzig from 1970 to 1990, which were reported in the "Scientific Reports of the Technical University of Leipzig", and the results of the "General Technology" working group of the Leibniz Society of Sciences and Humanities should be mentioned here. It should also be noted that the St. Petersburg State Technological Institute (Technical University) / St. Petersburg State Technological Institute (Technical University) has had a chair of "General Technology" for 60 years. The current activity of this Technical University is characterized by the unity of teaching and research in the fields of general technology and special technologies in materials management. Details are published on the website of this Russian technical university. The focus is on chemical technology and process engineering. Within the 5 faculties of this university, the Faculty of Information Technologies and Control and the Faculty of Engineering and Technology deal with issues of general technology. For example, at the Chair of Systems Analysis and Information Technologies, scientific activities are oriented towards mathematical modeling and optimization of technological processes. It is recommended to close the gaps in the analysis of publications on general technology. To this end, we want to contribute, which refers primarily to the development and application of quantitative methods in general technology based on mathematical modeling

Methodology of Mathematical Modelling

The methodology of mathematical modeling as a component of general technology is based on balance equations (material balance, energy balance, momentum balance). Figures 1,2 show the relationships used in mathematical modeling.

An impulse balance is often omitted.

At LIFIS, the following research and customer projects have been and are being carried out using methods of general technology:

- Design and control of horizontal fermenters
- Automated process for the production of diesel oil from organic waste and residues
- Project planning and control of decentralized, mobile and energy self-sufficient biogas plants
- production of agrosubstrate from sewage and fermentation residues
- Exhaust gas heat recovery in biogas plants for electricity generation
- Increasing the effectiveness of biogas plants by methanizing carbon dioxide
- Heat mobility.

The use of mathematical modelling methods is shown below using the example of increasing the effectiveness of biogas plants by methanation of carbon dioxide (see Figure 3). The innovative content of this project consists firstly in the production of green hydrogen by high-temperature electrolysis and secondly in the methanation of biogas (Figure 3).

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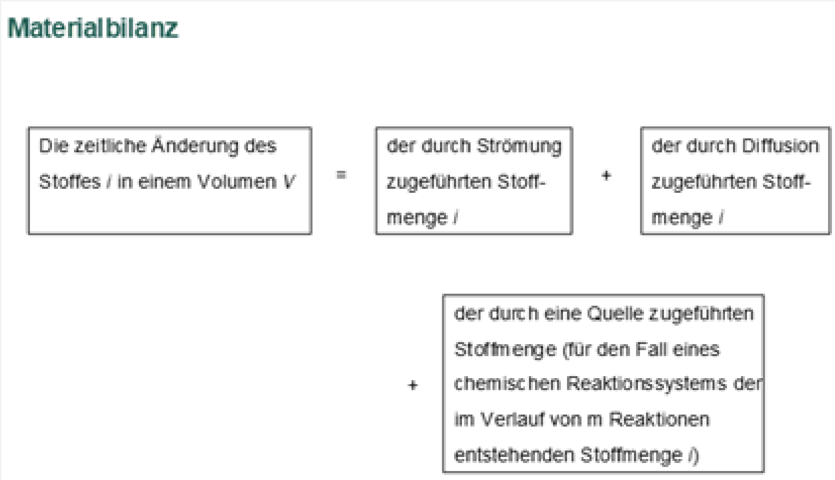

Figure 1: Basic equation of the material balance (own illustration).

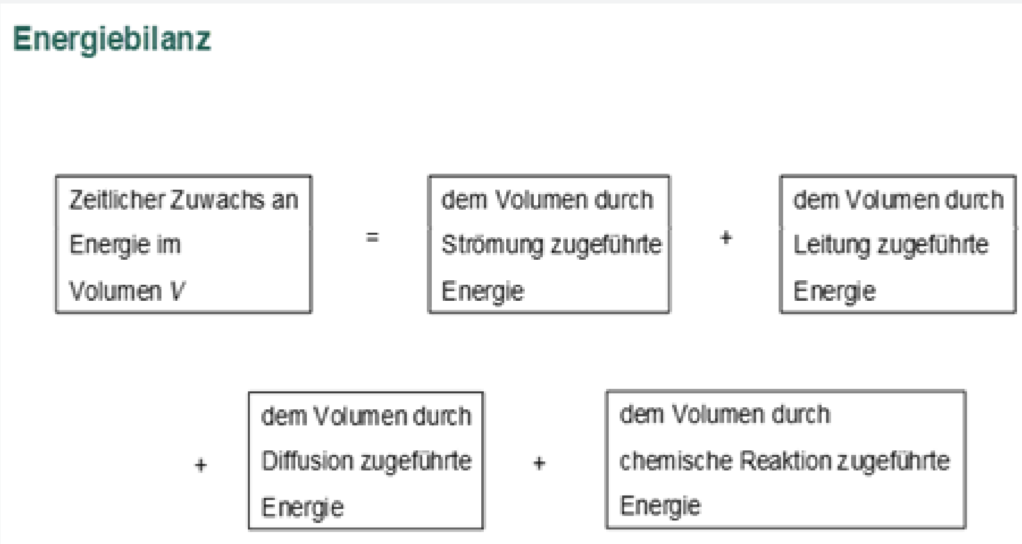

Figure 2: Basic equation of the energy balance (own illustration).

The mathematical model of the methanizer consists of two equations:

- **One-dimensional diffusion model (material balances)**

$$\frac{\partial x_i}{\partial t} + w\frac{\partial x_i}{\partial l} + D_L\frac{\partial^2 x_i}{\partial l^2} = \sum_i f_i(x_1, x_2, .., x_n, T) \qquad (1)$$

i = 1, 2, ..., n

x i (t, l) - concentration of component i

T (t, l) - Temperature

$f_i(x_1, x_2, .., x_n, T)$ =Reaction rate based on the formal kinetics of formation or consumption of component xi

w - linear velocity of the components in the reactor

DL - Longitudinal mixing coefficient

t - Time

l - running length of the reaction chamber

- **One-dimensional diffusion model (energy balance)**

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial l} + D_L\frac{\partial^2 T}{\partial l^2} = \sum_i h_i f_i(x_1, x_2, ..x_n T) + \alpha(T - T_k) \qquad (2)$$

T - Temperature of the reaction mixture

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Tk - temperature of the heating medium as a function of the length of the reactor and time

hi - coefficient dependent on the heat tint of the chemical reaction and on the specific heat capacity of the medium to be heated

l, t - running length of the reactor or running time

α - coefficient depending on the heat transfer properties

$f_i = \frac{d\alpha_i}{dt}$ -Responsiveness

The mathematical models described above are used for optimal design and control.

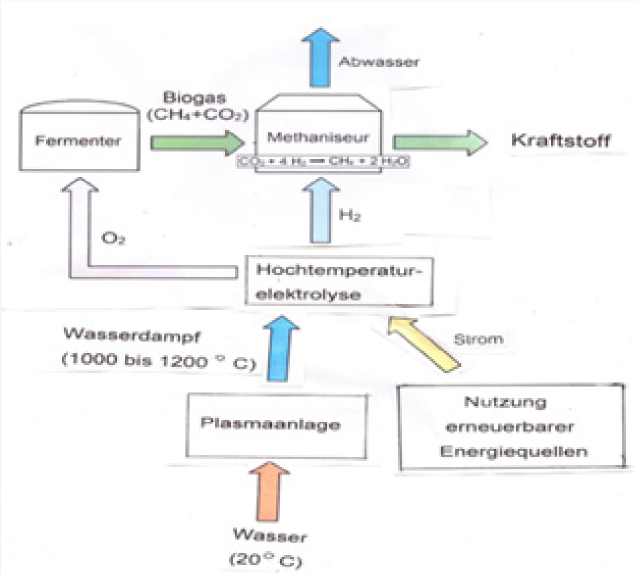

Figure 3: Increasing the effectiveness of biogas plants through methanation of carbon dioxide (own illustration).

Adequacy Test of Mathematical Models

To explain the principle of the adequacy test, we present the developed mathematical models in the following form:

$$\dot{y} = f(y, p, u, t,) \quad (3)$$

The following designations were used:

u_i - Input variables

y_i - output variables

p_i - system parameters (heat transfer area, heat transfer coefficient, kinetic constants, enthalpy of reaction, geometric dimensions, etc.)

For the adequacy test, the following two sums of squares must be compared:

Defect Sum of Squares

$$D = \sum_{i=l}^{N} (\tilde{Y}^{i} - y^{i})^2 \quad (4)$$

D represents an estimation of the difference between the theoretical output variables y^i and the transmitted or measured output variables $\tilde{y}$.

Sum of Squares of Errors

$$Q = \sum_{i=l}^{N} \sum_{j=l}^{M} (\tilde{Y}^{ij} - \tilde{y}^{i})^2 \quad (5)$$

Q represents an estimation of the measurement error. Usually, the estimation can be found in the documentation of the sensor supplier. M is the total number of measurements of the output quantity.

For the adequacy test of the theoretical and the measured process variables, the so-called Fisher criterion is used:

$$P(K < \varepsilon) = F_{\varphi_1 \varphi_2}(\varepsilon) \quad (6)$$

$$K = \frac{D/\varphi_1}{Q/\varphi_2} \quad (7)$$

φ_i represent the degrees of freedom of the sum of squares to be calculated and ε a boundary to be specified.

We specify P and determine the corresponding value for ε. If $K < \varepsilon$, the model is assumed to be adequate, otherwise not adequate.[00]

The unity of qualitative and quantitative methods of general technology in the design and reconstruction as well as in the safeguarding of technological systems

The model-based optimization of the structure and parameters of technological systems is carried out using algebraic methods and artificial intelligence methods.

Optimal Design

The optimal design uses a mathematical model of the steady state of the methanizer. The steady-state model is derived from equations (1) and (2) by

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$$\frac{\partial x_i}{\partial t} = 0 \text{ and } \frac{\partial T}{\partial t} = 0$$

can be set. The design parameters to be optimized are part of the sizes α and DL. The following is used as an optimization criterion:

$$F = x_{Methan}(L) \xrightarrow[Konstruktionsparamete]{} \max \quad (8)$$

where x methane(L) is the methane concentration at the outlet of the methanizer.

Optimal Control

Optimal control is firstly about completing the start-up and shutdown as well as the reversal processes as quickly as possible. Secondly, the aim is that during these dynamic processes the deviation from the optimal state is as small as possible.

Therefore, the following is used as an optimization criterion:

$$Q = \int_0^T \int_0^L \left[T(t,l) - T^{opt}(l)\right]^2 dldt \xrightarrow[V(t)_{Biogas}, V(t)_{Wasserstoff}, T(t,l)_{Heizwedium}]{} \max \quad (9)$$

In equation (9), the following designations were used:

$T(t,1)$ - temperature of the reaction mixture

$T^{opt}(1)$ - optimal temperature profile of the reaction mixture in steady state under the condition

$$x_{Methan}(L) \xrightarrow[V(t)_{Biogas}, V(t)_{Wasserstoff}, T(t,l)_{Heizwedium}]{} \max$$

Control variables:

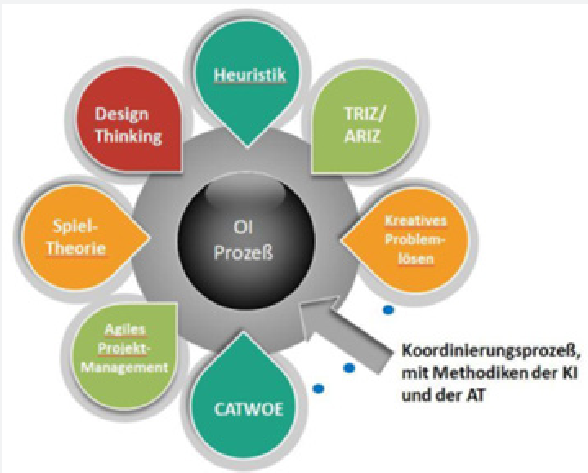
$V(t)_{Biogas}$ - Quantity of biogas/unit of time at the entrance to the methanizer

$V(t)hydrogen$ - quantity of hydrogen/unit of time at the entrance to the methanizer

$T(t,1)$ heating medium - temperature of the heating medium that varies over the length of the methanizer

In solving the optimization tasks (8) and (9), the mathematical models of the technological processes to be constructed and controlled are used as constraints. In order to successfully solve the above-mentioned tasks of design and control, a novel hierarchically structured model-based optimization method is used, which has two levels. At the lower level, the construction is optimized autonomously according to equation (8) using the following methods: Gauss-Seidel method, gradient method, steepest climb method. As a constraint, the mathematical model of the statics of the methanizer is used. In addition, at the lower level, the optimal control variables according to equation (9) are calculated autonomously using the maximum principle according to Pontryagin for systems with distributed parameters.

On the upper level, the design and control are coordinated. In addition, it is about the selection of fields of innovation and the organization of cooperation between the cooperation partners. In this context, the specification of the fields of innovation and innovation ideas on the one hand and the introduction and development of new innovation methods on the other hand are to be regarded as a single unit. This means that a variety of innovative methods have to be coordinated in a cooperative process of developing new solutions (Figure 4).



AI – Artificial Intelligence; AT – General Technology

Figure 4: Open innovation by coordinating innovation methods and creativity techniques (own illustration).

The coordination process includes, firstly, mathematical modelling as a replication of the static and dynamic properties of technological processes within the framework of general technology, and secondly, the execution of logical operations within the framework of artificial intelligence. In this context, general technology contributes to the modeling of business processes.

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Using methods from communication sciences and ergonomics, an OOI business model (OOI = Overall Open of Innovation) was created. In this model, external resources are divided into industrial and non-industrial units in order to be able to determine the methods of interaction between manufacturing enterprises and external resources. Particular attention is paid to the management of external resources involved in a TOI cycle (TOI = Technology Open Innovation). These include:

- The classification of the external resources of a TOI.
- The creation of general mechanisms or algorithms that can be used to select and use qualified resources and non-qualified resources.
- The creation of a business model for cooperation between companies and external resources.
- When developing the business models, the following questions must be answered:
- What types of external resources could be identified to facilitate the development of open innovation?
- What business model is required to develop cooperation between manufacturing companies and external resources during an open innovation process
- How can a manufacturing company apply a certain mechanism to effectively manage these external resources?

Model-Based Backup Systems

Model-based security mechanisms are primarily used with the aim of detecting and defending against attacks on the process control system of a technological plant (Figure 5).

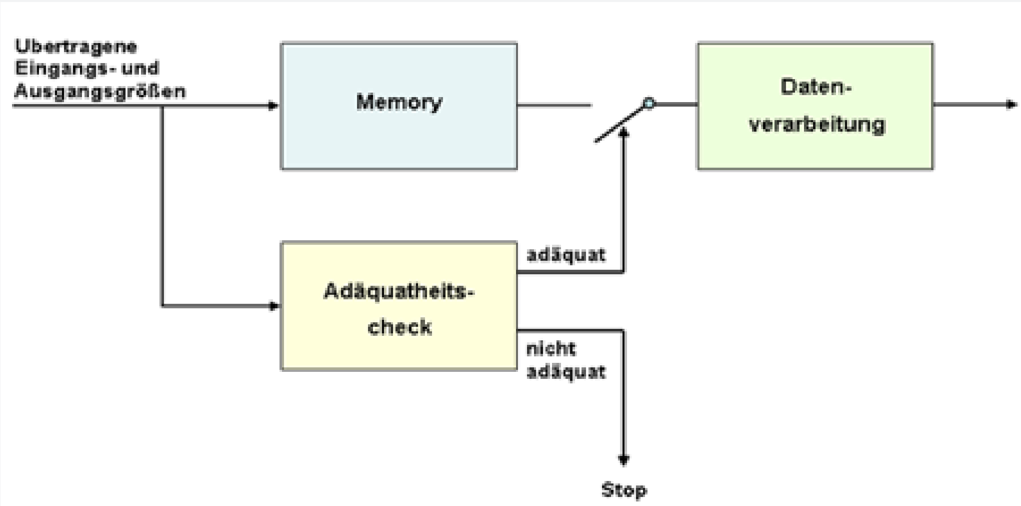

Figure 5: Structure of a model-based backup system (own illustration).

As a rule, knowledge-based or model-based algorithms are used. It is assumed that an adequate mathematical model exists for the control object (e.g. bioreactor, gas storage tank, combined heat and power plant) that describes the dependence of the output variables on the input variables. This means that the output variables can be calculated using the measured input variables and the mathematical model . The model-based security mechanism is located in the central part of the process control system. The algorithm itself consists of the following stages:

- Data acquisition of the input and output variables in the control object and data transmission (e.g. via the public network or Internet) to the central control system.
- Calculation of the theoretical output variables using the transferred input variables and the mathematical model.
- Comparison of the transmitted and calculated outputs and checking the adequacy of these two outputs using equations (3) to (7).
- In the event of a lack of adequacy (intrusion detection), data processing in the central control system is stopped (intrusion response).
- Identification of the causes of defective adequacy.

Control of external resources through vector optimization as a new method of general technology

The optimal management of external resources is a contribution of general technology to the development of science (cf. Balzer/Regen 2021). Particular emphasis is placed on human behavioral modeling as a qualitative method of general technology (Figure 6). In this context, the contribution of game theory is also described (cf. Leyendecker et al. 2021). In order to arrive at quantified optimal solutions in the use of external and territorially

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distributed resources of all kinds in the project planning and operation of technological plants, methods of polyoptimization (vector optimization) are used for the first time, in which several optimization tasks have to be solved by selecting the same design parameters and control variables:

$$I(x,u) = \{f_{01}(x,u), f_{02}(x,u), ..., f_{0m}(x,u)\} \rightarrow \max_u \quad (10)$$

$$f_{0i}(x,u) \rightarrow \max_u$$

$$i = 1, 2, ..., m$$

The following designations were used:

$I(x,u)$ - Overall objective function, which is a generalization of equations (8) and (9)

$f_{0i}(x,u)$ - subobjective functions

x - Process parameters

u - control variables, design parameters

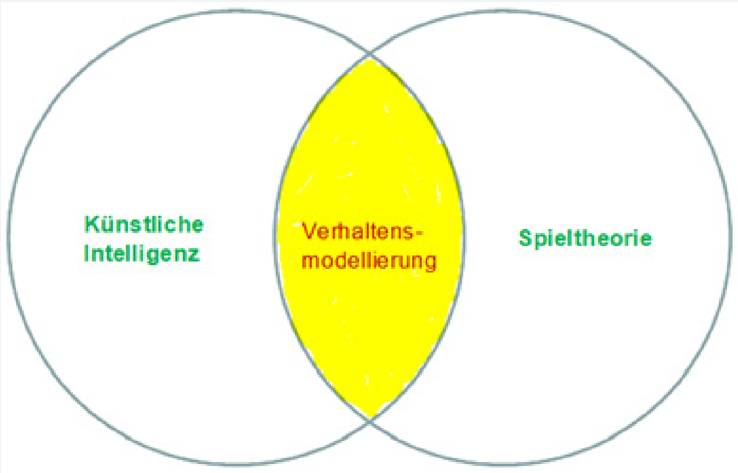

Figure 6: Behavioral modeling by combining artificial intelligence and game theory (Own presentation).

The behavioral models of humans (behavioral modeling) and the technological process or disposition (mathematical models) are integrated into the sub-objective functions.

The task described above is not correct in the sense of classical optimization theory. This incorrectness is overcome by coordinated application of artificial intelligence and game theory. There are two possible solutions:

✓ Transfer of the incorrect task into a classical optimization task with a scalar objective function.

✓ Determination of a compromise set (Pareto set): If no variation of the optimal control variables can increase the value of an arbitrary objective function without simultaneously decreasing the other objective functions.

We use the first solution. The transfer to a classic optimization task can be achieved with the following methods:

- Selection and optimization of the most important sub-objective function

$$I(x,u) = f_{0k}(x,u) \rightarrow \max_u \quad (11)$$

$$f_{0i}(x,u) = c_i$$

$$i = 1, 2, ..., K-1, K, K+1, ...m$$

- Introduction of weighting coefficients

$$I(x,u) = \sum_{i=1}^{m} \alpha_i f_{0i}(x,u) \rightarrow \max_u \quad (12)$$

$$\sum_{i=1}^{m} \alpha_i = 1 \qquad \alpha_i \geq 0$$

- Formation of global distance measures

$$I(x,u) = \sum_{i=1}^{m} \left[f_{0i}{}^{opt}(x,u) - f_{0i}(x,u) \right]^{\eta} \rightarrow \min_u \quad (13)$$

$$\eta \geq 0$$

The algorithms described above also provide the basis for the digitization of work processes.

We have decided to introduce weighting coefficients (Equation 12). since in this case the conflicts of interest between the operators of each decentralised system are the easiest to resolve

The control of external resources is carried out in two stages:

- Selection of coefficients α_i.
- Solving the optimization problem (12) by methods of artificial intelligence and algebraic methods.

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The selection of the coefficients α_i is carried out through game theory and coaching with the aim of resolving conflicts of interest between those responsible for the individual mobile biogas plants.

The causes of the conflicts are:

- perceived or actual competition.
- Procedural interests:
- psychological interests.
- Self-interest, self-interest.

Possible interventions include:

positions are in the foreground, therefore respond to interests and needs.

- Search for objectifiable criteria.
- Look for ways to expand the options and resources.
- Search for comprehensive solutions that best meet the interests and needs.

Negotiating more global solutions.

- Address equity aspects.

Development of biosystems process engineering as a new scientific discipline

The theoretical results described in points 2 to 4 were partly achieved and tested within the framework of the project "Project planning and control of decentralized, mobile and energy self-sufficient biogas plants". In the process, biosystems process engineering emerged as a new scientific discipline in which general technology acted as a driving force. An essential part of biosystems engineering is the integration of systems theory and biotechnological process knowledge. It is important to combine mathematical and information technology techniques with biotechnical material transformations.

The following content is relevant:

- Systems theoretical analysis of biotechnological plants.
- Mathematical modelling (kinetics, thermodynamics, hydrodynamics) of components and systems.
- sensitivity and stability.
- System optimization of biotechnological plants (design of the optimal structure and parameters);
- Optimal control of systems.

Role of Civil Engineering as a Universal Engineering Science within General Technology

Figure 7: The position of civil engineering within the technical sciences (own illustration).

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The position of civil engineering within the technical sciences is an important starting point for the development of general technology. Both the history of technical sciences and current theoretical and practical engineering activities show that civil engineering plays a central role in the development and application of engineering methods. Thus, already in the Middle Ages, the term engineer was associated with the activity of a master builder. In the 17th century, the word ingénieur (French) meant Professional in the technical field with theoretical training. Figure 7 shows the position of civil engineering within the technical sciences, which are often referred to as economized natural sciences.

Of particular importance are the relationships between civil engineering on the one hand and electrical engineering, process engineering, mechanical engineering and computer science on the other. The relationship to art is characterized above all by architecture. The influence of civil engineering on the development of general technology is primarily interdisciplinary. (A description of this aspect can be found in Sieber/Balzer 2021).

A striking example of the influence of civil engineering on the development of computer technology and computer science is the work of the civil engineer Konrad Zuse. Since static calculations in civil engineering were very time-consuming, Zuse came up with the idea of automating them. He therefore developed a calculating machine based on electromechanical relay technology (Figure 8). This was the first step towards converting the mathematical models into concrete software.

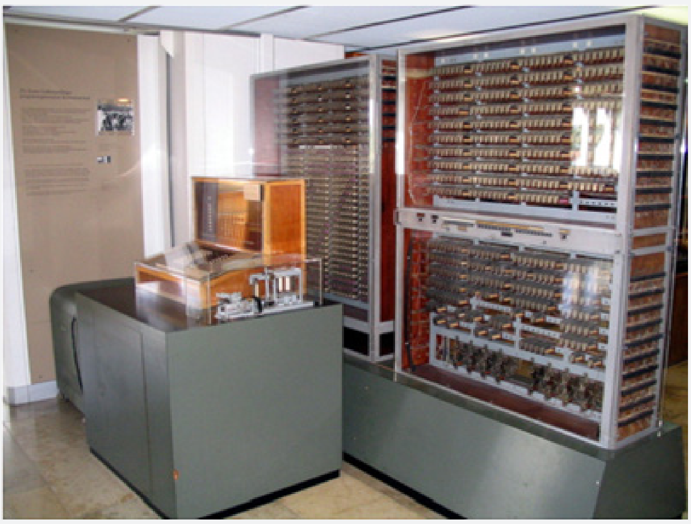

Figure 8: First electromechanical calculating machine Zuse Z3 (1941; Replica in the Deutsches Museum in Munich).

The influence of civil engineering on the development of science is particularly evident in the fact that new disciplines have emerged in teaching and research, such as: building physics, construction automation, construction informatics. In addition, construction automation as a new scientific discipline is discussed.

Since the beginning of the 1980s, the mechanization phase in the construction industry has been replaced by an automation and optimization phase with increasing application of computer technology. Electronic components and systems are first introduced in construction machinery selectively as a supplement and modification of conventional technology. Today, construction robots are mainly used in the automation of construction technology processes [1-7].

A high degree of automation has been achieved for years in stationary systems for mixing building materials (concrete and asphalt) and in the series production of standardized concrete products. The automated prefabrication of large format prefabricated reinforced concrete elements is developing rapidly. This applies above all to computer-aided (CAM) and computer-integrated manufacturing systems (CIM). Of particular importance is the automated control of transport, handling and storage processes (TUL processes) in construction technology. According to the degree of connection between the customer and the transport technology, there are:

- Technologically bound transport (e.g. transport of fresh concrete).
- Non-technological transport (e.g. container transport with finishing materials for complex housing construction).

This is determined by the degree of storage capacity of the goods to be transported.

The mathematical modeling and control of technological processes is based on decomposition into classes of process states:

- Undisturbed process with constant parameters.

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- Undisturbed process with scheduled changes of parameters.
- Disrupted process due to unknown and unpredictable changes in parameters.
- Accident with the need to prevent damage and hazards.

Important for modeling TUL processes in the construction industry, the following tasks are the solution: modeling of N-step decision-making processes, dynamic optimization in conjunction with real-time algorithms, balancing models for balancing transport services and demand, transport models using linear optimization (Figure 9). At the beginning of the 1980s, a special field of construction automation was launched for the first time in teaching and research at the Leipzig University of Applied Sciences together with the Bauakademie in Berlin.

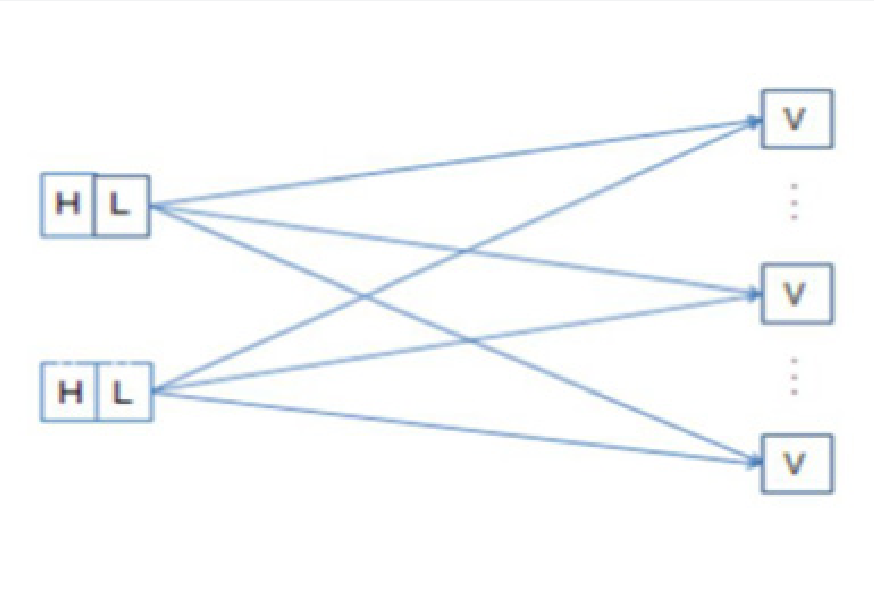

Figure 9: Example of a link between manufacturer (H), consumer (V) and warehouse (L) (Own illustration).

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